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RENE'95 BRAZED JOINT METALLURGICAL PROGRAM

FINAL REPORT

by

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RENE'95 BRAZED JOINT

METALLURGICAL EVALUATION PROGRAM

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I SUMMARY

Summary Introduction

This metallurgical program was specifically conducted for the establishment of material properties required for the design of the LF460 fan. The LF460 lift fan is an advanced 18:1 high thrust to weight single stage design. It has a turbine attached to the outer flowpath of the fan blade tip which minimizes the axial depth of the fan. Advanced lightweight attachment designs are employed in this concept to achieve minimum mass polar moments of inertia which are required for good aircraft flight response control. The design features which are unique to this advanced LF460 lift fan are the 0.010 inch thin Udimet 700 alloy integral tip turbine design, minimum weight braze attachment of the turbine to the fan blade, and the high strength and elevated temperature capability of the Rene'95 alloy for the fan blade. The Rene'95 material is selected for the fan blade because of its high strength to density at the 150°F fan flowpath and at the 1200° metal temperature required at the transition attachment between the turbine and the blade tip. In previous lift fan designs, a bolted clevis concept allowed the use of titanium blades to an Inconel alloy sheet metal turbine. The significant design advantage in the LF460 is the elimination of the high mass moment of inertia bolted attachment by the utilization of the integral design which brazes the blade directly to the turbine carrier side rails. This braze development and alloy test program is specifically directed toward obtaining stress design data for rupture, high and low cycle fatigue, thin wall effects on U700, which allows design optimization of stress and weight for the LF460 lift fan application. The technical data and material results of this study are provided in the following summary and are presented in comparison with the LF460 design stress. However, from a metallurgical viewpoint, the results are not limited to the LF460 exclusively and can be applied to any structural design utilizing combinations of Udimet 700, Rene'95 and Coast Metal 50 braze alloy.

The data presented in this report shows that the LF460 fan rotor design is feasible and that the design stresses and margins of safety were more than adequate. Prior to any production application, however, additional stress rupture/shear lap joints should be run in order to establish a firm 1200°F stress rupture curve for the CM50 braze metal.

The data in this report has been grouped into:

o <u>Braze</u> - Shear rupture
- Low cycle fatigue
- Braze fillet size
- Braze gaps
- Braze cooling cycle time

o <u>Parent Metal</u>

<u>Rene'95</u> - With and without braze cycle degradation for the LF460 braze alloy Coast Metal 50
- Notches effects
- Braze cooling rates
- Grain size

<u>U-700</u> - Degradation due to LF460 processing thin sheet effects, and braze surface interaction with the base parent alloy.

Braze

1. The best of the three braze alloys evaluated for the LF460 application was Coast Metal 50 (CM50) brazed at 2025°F for 10 MIN, furnace cooled to 1800°F in 22 MIN, then cooled to room temperature.
2. Nickel plating the U700 to a thickness of 0.0005 inch prior to braze reduced erosion significantly and is recommended in the R'95/CM50/U700 joint.
3. Strength evaluation of the simulated lift fan braze joint (a cruciform or "X" intersection of brazed plates) showed the joint exceeded design requirements for the LF460 application, as follows:

   A. Shear rupture strength at 1200°F for 100 hours:

      Test data ~ 12 KSI vs

      Design minimum = 11 KSI

   B. Low cycle fatigue life at 1200°F, σ_{peak} = 11 KSI, A = 0.98:

      Test data > 50,000 cycles vs

      Design minimum = 14,400 cycles

   Additional stress rupture/shear lap joints should be run in order to establish a firm 1200°F stress rupture curve for the CM50 braze metal.
4. Braze effects on strength were:

   A. Braze fillet surface roughness - negligible effect on cruciform rupture or LCF strength

   B. Braze fillet size - negligible effect on rupture

      - on fatigue, strength effect was small but large fillet size forced failure away from braze into adjacent U700.

   C. Braze gap effects on strength:

      - Cruciform rupture strength was insensitive to change in braze gap width from 0.003 inch to 0.010 inch.
      - Fatigue strength was only slightly more sensitive than rupture. Specimen with large gaps of 0.010 inch showed about 2 KSI less endurance strength (~ 20%) than 0.003 inch gap specimens.

- These trends provide a welcome flexibility of gap manufacturing tolerance for parts constructed with the R'95/CM50/U700 braze joint.

5. Slow cooling effect on braze strength:
   Increasing braze cycle cooling time from 10 to 22 minutes increased cruciform specimen rupture life by as much as 73 hours (385%) in the limited tests made. Fatigue specimens fabricated with the short cooling time had rough, partially cracked braze surfaces, while specimens exposed to the slower cool had much smoother braze surfaces. Only the slow, 22 minute cooling cycle is acceptable for fatigue loaded joints.

Parent Metal

1. R'95 and U700 as processed through the anticipated LF460 heat treat meet or exceed the strength requirements for the LF460 application.
2. Degradation of U700 fatigue properties due to LF460 processing, or to thin sheet effects, or to braze surface effects were negligible. Actual fatigue strengths were comparable to the best statistical samples tested to date.
3. Degradation of R'95 properties due to the LF460 processing were slightly more than anticipated:

Property		Value at Std.H.T.(1 (KSI)	Anticipated(2 Derate from Std. H.T. (%)	Test Data Derate from Std. H.T. (%)
Fatigue Strength	R.T.	86 (3	5	25
A = ∞	1000F	105	-	27
Stress Rupture Strength 1200F/100 HR		150	10	18
Ultimate Tensile	R.T.	235	-	11
Strength	1200F	212	3.5	12

1) Reference 1; 2) References 2 and 3; 3) Axial-Axial Data

The differences in anticipated and actual derates are mainly due to the modified braze slow cooling procedure.

4. Effects on R'95 strength were found due to:

Notches Tensile strength was reduced 5% to 12% due to large notches (K_T=3.0). Fatigue strength was more severely affected, showing reductions from peak stresses of 137 KSI with smooth samples to 56 KSI with K_T=3.0 notched samples (59% reduction). This decrease in notched strength is characteristic of very high strength heat treated alloys and was expected based on previous R'95 data.

Braze Cooling Rate The slow, 22 minute cool from the 2025 F braze temperature to 1800 F was picked in order to avoid potential braze cracking but is in opposition to the rapid quench R'95 needs to develop peak strength. As a result, some decreases in R'95 properties were accepted as a reasonable compromise for the gain in braze integrity, as follows:

- R'95 rupture was decreased a negligible amount
- R'95 fatigue strength was decreased 5%
- R'95 ultimate strength was decreased 7% at 1200 F and 20% at room temperature

Grain Size Duplex grain structure in R'95 is much desired over fine grain structure for the LF460 application because of the higher ductility in tensile and rupture and the higher rupture strength level.

Ductilities (as measured by R.A.) average 45% lower in tensile tests and 64% lower in rupture for fine grained versus duplex material.

Rupture life similarity averaged 20 hours less, or 72% in 150 KSI, 1200 F tests with the "22 minute" braze cycle.

II INTRODUCTION

Advanced design concepts that are based on new materials or unique material applications must be confirmed prior to manufacturing commitment. General Electric advanced lift fan designs employ the concept of Rene'95 fan blades brazed to Udimet 700 turbine blades. To insure the integrity of this concept and define the material properties for detail design, the Rene'95/Udimet 700 Parent Metal and Braze Joint Evaluation Program was initiated as part of the LF460 Fan Design Contract NAS2-6056.

The tentative manufacturing process identified for these brazed blades is:

1) Finish machine Udimet 700 (U700) buckets and stress relieve at 2135 F/4 HR/AC
2) Rough machine Rene'95 (R'95)
   Solution at 1650 F/24 HR and heat to 2000 F/1 HR/oil or salt quench
   Finish machine
3) Rene'41 (R'41) formed in annealed condition
4) Braze all parts at one cycle:
   2025F/22 MIN/FC to 1800 F/AC
5) Age brazed assembly at 1400F/16 HRS

Since this process subjected most of the materials to a non-optimum heat treatment, property evaluation of these "exposed" materials was desirable. The strength of this multi-material joint also required evaluation.

Specific Program objectives were:

- Selection of braze alloy and braze cycle
- Evaluation of braze joint strength
- Evaluation of Rene'95 and Udimet 700 after exposure to the brazing cycle

Design data required included:

- Brazed joint rupture strength
- Brazed joint fatigue strength
- R'95 tensile strength
- R'95 rupture strength

- o R'95 high cycle fatigue strength
- o U700 high cycle fatigue strength (0.010" thickness)

III SPECIMEN FABRICATION

Geometry to be Simulated

The brazed joint region was the major area of interest in this material test program. The geometry of this joint involved three materials: R'95, U700, and R'41 as shown in Figure 1. The brazed joint is the junction of the U700 turbine blade airfoil into the carrier base. The carrier base is a fabricated box structure consisting of the load carrying R'95 fan blade side rails and the non-structural R'41 0.010" sheet forming the inner flowpath surface. Since the R'41 pieces are non-structural only braze compatibility tests were scheduled for R'41, while strength design data evaluation was planned for R'95 and U700.

Specimen Material

R'95 was supplied in the form of 1-7/8" round and 2-5/8" round-cornered square bar stock, while U700 was supplied as 2" round bar stock. The R'41 was procured as 0.010" thick sheet. Vendor certification of these materials is compared with the specification chemistry and property requirements in Table I.

The yield strength of the Rene'95 bar stock was slightly low, but it was felt the material was completely satisfactory for the purposes of these investigations.

The three braze alloys procured were Coast Metal 50 (CM50), Coast Metal 53 (CM53) and B-84. Each was in powder form and their chemical compositions are listed in Table II.

Specimen Preparation - Parent Metal

The test evaluation requirements dictated the number and geometry of the test specimens. As shown in Table III, the parent metal program objectives were to evaluate U700 in axial-axial fatigue and R'95 in reversed bending fatigue, axial-axial fatigue, smooth and notched tensile strength, and stress rupture. All test coupons were machined from the rough bar stock into flat specimens.

The U700 high cycle fatigue tests would provide estimates of turbine blade strength under vibratory gas loads at elevated operating temperatures. Tests at two "A" ratios ("A" ratio = alternating stress/ mean stress) were planned to simulate the turbine blade steady state loading with various vibratory gas loads. Axial-axial mode tests were planned because they are simpler and may be used where the "A" ratio is less than one (an "A" ratio greater than one could cause undesirable buckling in an axial-axial test).

R'95 fatigue testing was oriented toward obtaining Goodman diagrams at three temperatures representative of: the hot side rail, the medium temperature seal, and the room temperature (R.T.) fan blade. These Goodman diagrams would be constructed using four points for each temperature: A = ∞, 0.45, 0.25, and 0.0 (where 0.0 is tensile or stress-rupture strength). Reversed bending tests were used for A = ∞ only, since axial-axial testing was impractical for this "A" ratio.

The notch tensile data was needed to compare with the smooth tensile data and thus evaluate notch effects on R'95 in both the R.T. fan blade and in the hot side rail.

The R'95 side rail stress rupture property evaluation was needed to determine the hot, long-time strength in the material adjacent to the R'95/U700 braze joint. The detail geometry of all parent metal test specimens is shown in Figures 2 through 6.

Possible braze effects on fatigue properties of the LF460 U700 bucket were investigated through the use of the specimen shown in Figure 7. This specimen was initially machined to the same dimensions as the parent metal U700 fatigue specimen (Figure 6). Then top and bottom surfaces in the gage section were coated with braze powder and the specimen subjected to two braze cycles. The excess surface braze was then removed by grinding the gage section to finish dimensions. This resulted in a U700 specimen having surface material in the gage section exposed to any potential braze degradation effects.

Specimen Preparation - Brazed R'95/U700

Three basic types of brazed test specimens were used in the program

outlined in Table IV; two for braze alloy selection and one for braze joint evaluation.

To screen various braze alloy candidates and compare their relative merits, a "T" joint specimen shown in Figure 8 was used for wettability and erosion comparisons while the "1t" overlap-joint tensile specimen shown in Figure 9 was used to measure tradeoffs in tensile and rupture strength. Additionally, the "1t" overlap braze joint provided evaluation of large surface wetting characteristics not available from the simple "T" joint testing.

The cruciform/simulated-joint specimen shown in Figure 10 is a special design created to evaluate joint strength. It was modeled to closely simulate the actual geometry of the LF460 lift fan braze attachment between the U700 turbine blade and the R'95 side rail shown previously in Figure 1. These cruciform test specimens were used for both stress rupture with 4.3 t overlap geometry and combined low cycle fatigue testing with 30 t overlap.

The cruciform specimens were fabricated in a 5 specimen fixture. The R'95 portion of each specimen was placed in a horizontal position with the mating U700 piece oriented vertically. Both pieces were clamped in place and the braze alloy slurry placed on the flat R'95 at the end of the U700 piece. Under furnace heating in high vacuum (10^{-4} torr), the braze flowed down the length of the R'95/U700 junction.

Most stress rupture cruciform specimens were made with 0.070" thick U700 in the test section but several were made with 0.010" thick U700. All of the cruciform specimens for combined stress fatigue were fabricated with 0.010" thick U700 in the test section.

Heat Treatment

For both the parent metal and the brazed specimens all the machining was performed with the material in the solution treated condition. Subsequently, the specimens were brazed (simulated braze for parent metal) and then aged in a vacuum. Table V shows the various specimen fabrication heat treat sequences employed.

IV BRAZE ALLOY AND PROCEDURE SELECTION

Three braze alloys (CM53, CM50 and B84) were evaluated for the R'95/U700/R'41 joints with regard to their wetting, flow, erosion and relative strength characteristics. CM50 with a 2025°F/10 MIN cycle was chosen as the best braze alloy candidate for the R'95/U700 joint and was used for the braze joint property evaluation program. This decision was based on the good wetting and flow characteristics of CM50, its negligible erosion of R'95, U700 and R'41, and its adequate strength level.

The braze alloy selection process was based on both metallurgical compatibility studies and on comparative strength evaluation. The metallurgical phase was based on microstructural study of "T" joints. The compositions of the braze alloys studied was given previously in Table II and the parent metal combinations, times and temperatures investigated are presented in Table VI.

Parent metal was studied in the nickel plated and unplated conditions. Brazing temperatures of 1975°F and 2025°F and times of 5 and 10 minutes were evaluated. Plating a layer of 0.005 inch nickel improved the wetting and flow of braze alloys on U700 and Rene'41. Braze flow was good at 1975°F for CM50 and CM53, but 2025°F was necessary for good flow in B84. Braze gaps of 0.003 - 0.005" were required to insure complete flow along the joint when using CM53 and B84. Satisfactory flow was obtained when CM50 was used with gaps of 0.001 - 0.005".

Microscopic study indicated that B84 was the most erosive braze alloy overall for the parent alloys studied. Both CM53 and B84 were very erosive to U700 and R'41 with a brazing time of 10 minutes. The amount of erosion was significantly reduced by using nickel plate. Typical photomicrographs of 0.010" thick U700 brazed to R'95 with and without nickel plate and brazed 10 minutes at 2025°F are shown in Figures 11 through 16. The reduced erosion by CM50 as compared to CM53 and B84 is evident. The beneficial effects of nickel plating are particularly noticeable for CM53. However, even nickel plating could not adequately reduce the severe B84 erosion.

Tensile lap shear tests at 1300°F were conducted on R'95/U700

specimens brazed with three different braze alloys. The results are shown in Table VII.

V BRAZED JOINT EVALUATION

Braze cycle #1 of 2000 F with a 10 minute cool was initially chosen in the early program work but was later modified to the #2 cycle at 2025 F with a 22 minute cool. This #1 cycle had the desirable features of adequate wetting, flow and crack-free fillets and was established in part using flat "1t" overlap specimens. This type of configuration is customary for braze alloy strength evaluation. However, accurate evaluation of the LF460 braze junction demanded a special type of test specimen. This need was filled by the design of the cruciform brazed test specimen. The cruciform specimen required different preparation and fixturing methods from the "1t" specimen. In the course of making cruciform brazed specimens for rupture and fatigue testing, various specimen fixtures and brazing techniques were explored to better establish the basic brazing cycle parameters. It had been determined that to maintain high strength in the Rene'95 parent metal, it was desirable to fast cool from the braze temperature (2000 F). However, some roughness/cracking was observed on the fillet surfaces of specimens prepared in this manner. The indicated corrective action was to increase the brazing temperature slightly and slow the initial portion of the cooling cycle. Cooling times of 18 and 25 minutes to 1800 F, as compared to the original 10 minutes, were evaluated.

These minor changes in brazing procedure resulted in improved fillets, as expected. To insure that R'95 processed to this modified braze cycle would meet the design requirements, some R'95 testing was done. Rene'95 flat tensile specimens were given simulated braze cycles using the slower cooling rates of 18 and 25 minutes to 1800 F. Room temperature and 1200 F tensile tests were conducted and the results are shown in Table VIII and plotted in Figure 17 in comparison with the 10 minute cooling cycle. The decrease in R'95 tensile properties was in agreement with the derate originally forecast. It was expected that this change in braze cycle would have little effect on rupture

properties. Evaluation of several R'95 rupture specimens given the slower cool braze cycle verified the strength required by the LF460 design (see data in Section VI, p.14).

Cruciform rupture specimens also were evaluated with the higher brazing temperature (2025 F) and slower cooling times (18 and 25 minutes) to 1800 F. All specimens were tested at a level where previous tests had been run. The results are shown in Table IX and Figure 18. Based on these results, cruciform rupture specimens made with the 2025 F braze temperature using 18 to 25 minute cooling time to 1800 F would have greater rupture strength than those given the 2000 F braze temperature with only 10 minute cooling to 1800 F.

As a result of the above finding, all the cruciform specimens for combined stress fatigue testing were fabricated using the modified slow 22 minute braze cycle (Cycle #2).

The results of this modified,22 minute slow cooled braze cycle satisfied the three design requirements:

1. Crack-free braze fillets
2. Improved braze joint rupture strength
3. R'95 parent strength acceptable to the LF460 original design calculations.

<u>Rupture Testing</u>

The results of shear tests on "1t" overlap joints were discussed earlier in Section IV page 8 under braze alloy selection. The data on cruciform rupture specimens is presented in Table X and Figure 18. The values shown include U700 test section thickness of both 0.010 and 0.070 inch. All failures occurred in the braze joint. Photos of the failure surfaces are shown in Figures 19, 20, and 21.

A limited investigation of braze gap effect on cruciform rupture strength was conducted. As seen from the data in Table IX and Figure 22, the 0.010 inch gap specimens exhibited as good or better rupture strength than the 0.003 inch gap specimens. However, no major strength difference was noted.

<u>High Cycle Fatigue (HCF) Testing</u>

Evaluation of HCF joint properties was planned through the use of

cruciform simulated-joint specimens similar to those used in rupture joint evaluation. Examples of cruciform test specimens are shown in Figure 23, together with a closeup of the braze fillet surface of one specimen in Figure 24. Test data from the axial-axial tests is shown in Tables XI, XII and Figures 25, 26 and 27. Observations were made as to:

1. Fillet roughness effect on strength
2. Fillet/failure location correlation
3. Stress distribution: actual vs assumed.

Minor braze fillet roughness in some specimens was noted but found to have no measurable affect on joint fatigue strength. However, fillet size affected the location of specimen fatigue failures.

Small filleted joints appeared to induce failure in the braze. On the other hand, large filleted joints seems to reinforce the braze, diverting the failure location to the parent metal (U700).

These various types of failures are shown in Figure 28. Figure 28C shows a random type failure where an inaccurately positioned thermocouple tack weld appears to have induced a large stress concentration. Figures 28A and B are typical test failures. "A" is representative of a large braze fillet forcing a U700 failure in the braze affected zone. "B" shows a smaller, weaker braze fillet where failure developed in the braze. Photos and micros of these failures are shown in Figures 29 through 39.

A further examination was made of the fatigue test data and specimens together with a review of analytical work and test experience on full size lift fan hardware. It showed that the actual fan braze joint is lower stressed in high cycle fatigue (HCF) than the cruciform test sample. This indicates that the cruciform is not a good HCF model of the full design hardware and is a better model for low cycle fatigue and rupture. A truly valid HCF test of the braze joint could not be made with the simplified geometry model but would require a 3-D, exact geometry specimen. Previous GE lift fan experience that further illustrates these points is in three areas:

I Stress Analysis

II Bench Tests

III Field Operation

The next section provides an evaluation of these three areas.

HCF Testing - Stress Analysis

Vibratory blade loads are not developed in the braze joint but in the supporting structure as shown in Figures 40, 41 and 42. Figure 40 shows the full scale design geometry planned for the LF460 blade/turbine structure while Figures 41 and 42 are local areas of the same geometry showing the construction details. Figure 42 illustrates the local blade/box/side rail braze joints and the free body force diagrams. As shown by these figures, the cruciform test specimen simulates the side rail to turbine blade braze joint. From Figure 42A, it can be seen that the centrifugal loading is taken directly by this joint. Thus, the cruciform tests for steady state rupture and stop-start LCF are accurate evaluations of the stress in the braze joint. Vibratory loading should not be approached in the conservative manner as shown in Figure 42B. Instead, the more accurate analysis of Figure 42C should be applied to stress calculations of the turbine blade support structure.

HCF Testing - Bench Tests

All bench tests of GE lift fan turbines have shown the blade braze joint is lightly loaded in HCF. When full size turbine hardware was tested to failure in HCF, the cracks always appeared outside the braze joint in the blade parent material.

A specific example of the braze joint strength is the bench test evaluation of the LF336 Turbine Carrier high cycle fatigue (HCF) strength as reported in Reference 4. This evaluation was initiated with fixed mounting of a turbine carrier to a shake table and determination of the basic turbine blade resonant frequencies. The turbine was then vibrated at these resonant frequencies at increasing stress levels until failure occurred. All failures were found to occur outside the braze joint. Figure 43 shows a representative HCF crack.

This failure crack is located in the blade parent metal above the braze fillet.

The failure location can be classified as being in the braze-affected zone. This is the area physically outside the braze fillet but metallurgically transformed by braze interaction with the parent metal. The strength of this area is affected by the braze and could be lower than parent metal strength.

The failure location near the blade root further demonstrates that the turbine bucket stresses are geometry dependent and the braze joint stress is much lower than that of the airfoil.

<u>HCF Testing - Field Operating</u>

GE field operation of lift fans does not develop large HCF stresses in the turbine blade braze joint. Field performance by General Electric lift fans (LF1, X376, and LF336) over a period of ten years has shown these stresses to be low since there has never been a turbine braze failure.

<u>HCF Testing - Summary</u>

Several conclusions can be drawn from the analysis and test areas:

1) In HCF, the turbine blade base is a rigid, redundant, 3-D structure where stress is geometry dependent.
2) The highest blade HCF stress occurs in the turbine airfoil.
3) For a wide range of blade and support structure materials, the geometry dependence of HCF stresses will cause turbine blade HCF failures to occur away from the braze joint.

Based on these observations, combined fatigue testing of the cruciform braze specimens was continued on an LCF basis. The LCF test program concentrated on the A = 1.0 data points (start-stop cycles are A = 1) and was oriented toward cyclic life values of 50,000 cycles or less. This corresponds to the quoted NASA Remote Fan life of 40,000 cycles and the NASA LF460 Lift Fan life of 14,400 cycles. As seen in Figure 26, the required LF460 life can be easily met.

VI PARENT METAL EVALUATION

U700 - Fatigue

The results of the U700 high cycle fatigue tests are shown in Table XIII and Figure 44 for parent material and is compared with test data on braze affected U700 and standard design data in Table XIV and Figures 45 and 46. The basic U700 fatigue strength is better than expected and appears to show no degradation in strength due to thin sheet effects. Similarily no significant drop in strength was found due to surface braze effects.

R'95 - Tensile

Tensile testing of parent metal Rene'95 was performed on smooth specimens at R.T., 1000, 1200, 1300, and 1400 F. Notched specimens were tested at R. T. and 1200 F. The resultant values are tabulated in Table XV. These data are from specimens given the 2000 F/10 MIN cool simulated braze cycle. As explained earlier, additional tensile tests were conducted on specimens with slower cool cycles. As listed previously in the conclusions, the 12 percent drop in 1200 F strength is slightly more than the 3.5 percent originally anticipated.

R'95 - Rupture

Stress rupture tests were performed on parent metal Rene'95 specimens at 1000, 1200, 1300, and 1400 F to check 100-hour rupture strength. The results of these tests are listed in Table XVI and plotted in Figure 47 in relation to forged material given the standard Rene'95 heat treatment. As with the tensile properties given above, these rupture values were obtained using the 2000 F/10 MIN cool braze cycle. Because of the change necessitated in braze procedure, some additional Rene'95 parent metal rupture specimens which were available were given the "new 22 minute" braze cycle and tests were run at 1200 F. These results (filled circles) are also shown in Figure 47. As was expected, no significant change in Rene'95 rupture properties (compared to original 10 minute braze cycle) was observed. A micro of a typical failed rupture specimen is shown in Figure 48.

DS

R'95 - Fatigue

The HCF data are presented in Tables XVII through XX and are plotted in Figures 49 through 54. This data includes several retests run at A = 0.45 and ∞ to investigate such affects as surface finish and cooling cycle.

The test data has been converted into modified Goodman diagrams at room temperature and 1000 F in Figures 55 and 56 to account for slow cool effects. As shown when compared with LF460 design stresses, slow cool processed R'95 exceeds the LF460 requirements.

R'95 - Microstructural Effect on Properties

One of the primary purposes of this program was to determine if the decrease in Rene'95 properties due to special braze processing was of the order of 12-15 percent as predicted.

A detailed study was made regarding the characteristics of Rene'95 with specific attention given to the variation in microstructure and properties for different mill forms. Rene'95 is strengthened by the combined effects of:

1) Alloying element solid solutioning,
2) Precipitation hardening, and
3) Residual warm work.

This third effect is achieved by finish forging below the recrystallization temperature. Because of the limits of thermomechanical processing imposed by different section sizes, forgings and bar stock processed by the same basic mill practices have different structures and properties. Forgings are characterized by a duplex microstructure which consists of large unrecrystallized grains surrounded by a "necklace" of fine recrystallized grains. This type of microstructure is depicted in Figure 57. Additionally, because of the greater amount of reduction involved in its production, bar stock typically displays a uniform fine grained (fully recrystallized) microstructure as shown in Figure 58. In general, Rene'95 bar stock has lower tensile and rupture ductility than forgings. This relationship between bar stock

and forging ductilities remains the same after exposure to braze heat treatment, but fine grain rupture strength is more severely reduced.

To obtain full strength properties in Rene'95, it is necessary to either oil or salt quench from the solution temperature (2000 F). In brazing design application, the cooling rate, of course, cannot be this rapid.

Typical properties of Rene'95 bar stock (fine grain) and forgings (duplex) with standard heat treatment and after braze heat treatment are shown in Table XXI, and illustrate the strength/ductility advantages of the duplex structure. Although fine grain R'95 was used for evaluation in this program, duplex structure would be procured for LF460 type hardware applications.

VII REFERENCES

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2) Grate, F. E.; Fatigue Properties of Rene'95; General Electric Report #TM71-570; 7/13/72

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TABLE I

CERTIFICATION DATA

UDIMET 700 AND RENE' 95 BAR STOCK, RENE' 41 SHEET

Composition (wt %)

	Rene' 95		U700*		Rene' 41
Element	Heat No. 7964	General Electric Specification C50TF38-S1	Heat No. 7336	General Electric Specification C50TF24-S1	Specification AMS 5545
C	0.138	0.13/.17	0.125	0.10/.15	0.12 MAX
S	0.005	0.015 MAX	0.005	0.015 MAX	0.015 MAX
Mn	0.01 MAX	0.15 MAX	0.10 MAX	0.15 MAX	0.10
Si	0.10	0.20 MAX	0.01 MAX	0.20 MAX	0.50 MAX
Cr	14.37	13.00/15.00	14.50	14.00/15.25	18/20
Mo	3.52	3.30/3.70	4.16	3.90/4.00	9/10.5
Co	8.32	7.00/9.00	15.20	14.25/15.00	10/12
Ti	2.47	2.30/2.70	3.35	3.00/3.70	3/3.3
Al	3.37	3.30/3.70	4.31	4.00/4.60	1.4/1.6
B	0.011	0.006/.015	0.016	0.012/.020	0.003/.01
Zr	0.05	0.03/.07	0.02	0.04 MAX	--
Fe	--	0.50 MAX	0.40	0.50 MAX	5 MAX
Cu	--	--	0.10 MAX	0.10 MAX	--
Ni	Bal	Bal	Bal	Bal	Bal
P	0.005	0.015 MAX	--	--	--
Cb + Ta	3.47	3.30/3.70	--	--	--
W	3.47	3.30/3.70	--	--	--

*Certified to chemistry only

TABLE I (Continued)

Rene'95 Creep**

	Temp (°F)	Stress (KSI)	Life (Hrs)	Elongation (%)
Heat 7964	1100	150	100.5	0.089
C50TF38-S1	1100	150	100.0	0.200 Max.

Rene'95 Tensile Strength **

	Temp(°F)	UTS (KSI)	.2% YS (KSI)	.02% YS (KSI)	% EL	% RA
Heat 7964	Room	235.5	178.7	172.0	19.4	21.0
	1200	217.3	170.0	155.0	11.7	13.0
C50TF38-S1 Class B minima	Room	230.0	186.0	--	10.0	15.0
	1200	207.0	172.0	--	10.0	15.0

**Heat Treatment: 1950/4hr/AC
1650F/24hr elevated to
2000F/1hr/OQ
1400F/16hr/AC

U700 Properties***

1300 F	UTS	163.5 KSI	
	0.2% Y.S	116.4 KSI	
	Elongation	24.5%	
	R.A.	38.6%	
1800 F	18,000 Psi	Rupture	57.7 Hours
		Elongation	12.5 %
		R.A.	17.5 %

*** Vendor Data

TABLE II

LIFT FAN BRAZE ALLOYS

Alloy	Nominal Composition (wt %)						
	Cr	Si	B	Fe	Ni	Al	Ti
AMS 4779 (CM50)	--	3.5	1.9	--	Bal	--	--
AMS 4777 (CM53)	7.0	5.0	2.9	--	Bal	--	--
B-84	--	8.0	4.0	15.0	Bal	3.0	2.0

TABLE III

MILESTONES - PARENT METAL EVALUATION

Alloy	Specimens	Mode	Conditions	Testing Start	Testing Completion
		Fatigue			
Rene' 95	18	Rev Bend	$A = \infty$ RT, 1000, 1200°F	7/6/71	7/30 (RT) 9/27 (1000°F) 10/28 (1200°F)
Rene' 95	30	Ax-Ax	A = 0.25:RT,1000, 1200°F A = 0.45:RT	8/11/71	9/30
U700	12	Ax-Ax	A = 0.25, 0.45 1400°F	8/6/71	9/30
		Tensile (Smooth)			
Rene' 95	15	-	RT, 1000, 1200 1300, 1400°F	9/15/71	9/20
		Tensile (Notch)			
Rene' 95	6	-	RT, 1200°F	9/21/71	9/26
		Stress Rupture			
Rene' 95	12	-	1000, 1200 1300, 1400°F	9/15/71	10/26 (1400°F) 11/30 (1000, 1200 1300°F)

TABLE IV

MILESTONES - U700/R95 BRAZED JOINT EVALUATION

Joint Type	Braze Alloy	Specimens	Testing Mode	Testing Conditions	Testing Start	Testing Completion
1t Overlap	CM50	3	Tensile	1300°F	6/22/71	8/3/71
1t Overlap	CM53	3	Tensile	1300°F	6/22/71	8/3/71
1t Overlap	B84	3	Tensile	1300°F	6/22/71	8/3/71
1t Overlap	CM50	2	Shear Rupture	1300°F, 100 hours	7/28/71	8/20/71
1t Overlap	CM53	2	Shear Rupture	1300°F, 100 hours	8/10/71	8/27/71
1t Overlap	B84	2	Shear Rupture	1300°F, 100 hours	8/10/71	8/31/71
Simulated Joint	CM50	2	Proof Rupture	1300°F, 100 hours	8/26/71	8/31/71
Simulated Joint	CM50	5	Shear Rupture	1200°F, 100 hours	9/27/71	11/22/71
Simulated Joint	CM50	5	Shear Rupture	1400°F, 100 hours	9/20/71	11/29/71
Simulated Joint	CM50	12	Combined Fatigue	1200°F, A = 0.45, 1.0	12/1/71	1/31/72
Simulated Joint	CM50	12	Combined Fatgiue	1400°F, A = 1.0	12/1/71	1/31/72

TABLE V

SPECIMEN FABRICATION HEAT TREATMENT

Specimen Type:	Rene'95	U700	Brazed R'95/CM50/U700
Condition Received	1950 F Stress Relief	2135 F/4 HR/AC	1950 F Stress Relief (R'95) 2135 F/4 HR/AC (U700)
Solution Treat:	1650 F/24 HR Elevate to 2000 F/ 1 HR/OQ	Not Required	1650 F/24 HR Elevate to 2000 F/1 HR/QQ (R'95 only)
Braze Cycle:	#1) 2000 F/10 MIN+ 10 MIN Cool	2000 F/10 MIN+ 10 MIN Cool	2000 F/10 MIN + 10 MIN Cool
	#2) 2025 F/10 MIN+ 22 MIN Cool	2025 F/10 MIN+ 22 MIN Cool	2025 F/10 MIN + 22 MIN Cool
Age:	1400 F/16 HR	1400 F/16 HR	1400 F/16 HR

TABLE VI

SCOPE OF BRAZED "T" JOINT EVALUATIONS

Braze Temp.	1975°F						2025°F					
Time at Braze Temp.	5 Min.			10 Min.			5 Min.			10 Min.		
Braze Alloy	CM50	CM53	B-84	CM50	CM53	B-84	CM50	CM53	B-84	CM50	CM53	B-84
Parent Metal Comb.												
U700-R'95	X	X	X				X		X	X	X	X
U700(Ni*)-R'95				X	X	X				X	X	X
R'41-R'95	X	X					X		X	X	X	X
R'41 (Ni*)-R'95				X	X	X				X	X	X
U700-R'41	X	X	X	X	X	X	X		X	X	X	X

*Nickel Plated Prior to Brazing

TABLE VII

PRELIMINARY BRAZED JOINT EVALUATION

Rene' 95/U700 Braze Test Results

Specimen No.	Braze Alloy	Specimen Geometry	Temperature (°F)	Stress[2] (KSI)	Time to Failure (hrs)	Failure Location
		TENSILE TESTS				
1	CM50	1T Overlap 0.125 thk	1300	53.7		Braze
2	CM50	"	1300	44.9		Braze
3	CM50	"	1300	56.6		Braze
4	CM53	"	1300	46.0		Braze
5	CM53	"	1300	54.6		Braze
6	CM53	"	1300	55.0		Braze
7	B84	"	1300	38.1		Braze
8	B84	"	1300	44.0		Braze
9	B84	"	1300	57.4		Braze
		Braze Screening Rupture Tests				
1	CM50	1T Overlap 0.125 thk	1300	45.0	0.01	Braze
2	CM50	"	1300	25.0	2.4	Braze
3	CM53	"	1300	20.0	142.0	R.O. (1)
			1400	20.0	117.0	R.O
			1550	20.0	1.0	Braze
4	CM53	"	1300	30.0	92.0	R.O.
			1550	30.0	0.1	Braze
5	B84	"	1300	35.0	4.5	Braze
		Cruciform Proof Tests				
1	CM50	Cruciform 0.01 thk U700	1300	30.0	0.2	Braze
2	CM50	Cruciform 0.07 thk U700	1300	20.0	2.0	Braze

(1) R.O. = "Run Out" with no failure, specimen then steploaded to next stress level.

(2) Stress = indicated shear stress = load ÷ wetted area

TABLE VIII

EFFECTS OF COOLING RATE ON RENE' 95 TENSILE PROPERTIES

Cooling Rate	Standard Heat Treat			2000 - 1800°F 10 Min			2025 - 1800°F 18 Min			2025 1800°F 25 Min		
	TENSILE PROPERTIES (KSI)											
	Ult	0.2%	% El	Ult	0.2YS	% El	Ult	0.2YS	% El	Ult	0.2YS	% El
R.T.				227.9	174.8	20.4	222.2	153.6	23.[illegible]	223.6	153.3	24.4
				231.2	182.4	20.8	225.0	153.3	24.1	225.8	152.[illegible]	2[illegible].3
				224.8	175.[illegible]	1[illegible].6	—	—	—	—	—	—
Avg	235	191	19.4	228.0	177.6	19.3	223.6	153.4	23.9	224.7	152.8	23.8
1200°F				202.8	154.2	15.6				187.1	142.7	17.3
				205.0	149.1	16.6				184.5	139.7	18.4
				202.1	157.1	14.0				-	-	-
Avg	217	170	11.7	203.3	154.0	15.4				186.0	142.0	18.2

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TABLE IX

COOLING AND GAP VARIATION EFFECTS

ON CRUCIFORM RUPTURE STRENGTH

-RENE' 95/CM50/U700 BRAZED JOINT

Cooling Effect	Cooling Rate	Time to Rupture (Hrs)
Base Case #1	2000-1800°F/10 Min.	14.8 (Avg of 2 Specimens)
Case #2	2025-1800°F/18 Min.	71.6 (Pin Failure)
	2025-1800°F/18 Min.	128.3
Case #3	2025-1800°F/25 Min.	64.3

All Specimens: U700 thickness = 0.070 inches
1400°F, 9 KSI
Failures in braze unless noted otherwise

Braze Gap Effect

Specimens below have 0.010 nominal braze gaps compared with the 0.003 nominal braze gap for all other specimens tested.

Specimen	Temperature (°F)	Stress (KSI)	Time to Rupture (Hrs.)
1	1200	20.0	22.5
2	1200	15.0	354.2 (R.O.)
2	1300	15.0	5.9
3	1200	17.0	252.2

TABLE X

CRUCIFORM RUPTURE STRENGTH TEST RESULTS

RENE' 95/CM50/U700 BRAZED JOINT (10 MINUTE COOLING RATE DATA)

	Specimen	U700 Thickness (Inches)	Temperature (°F)	Stress (KSI)	Time to Rupture (Hours)	Failure Location
Proof Tests	1	0.01	1300	30.0	0.2	Braze
	2	0.07	1300	20.0	2.0	Braze
Evaluation	1	0.01	1400	13.0	6.0	Braze
	2	0.01	1400	9.0	22.2	Braze
	3	0.07	1400	13.0	1.3	Braze
	4	0.07	1400	9.0	9.3	Braze
	5	0.07	1400	9.0	20.3	Braze
	6	0.07	1400	6.0	67.95	Braze
	7	0.07	1400	8.0	21.2	Braze
	1A	0.07	1200	19.1	63.3	Braze
	2A	0.07	1200	19.1	23.0	Braze
	3A	0.07	1200	15.0	256.5	Braze
	3A	0.07	1400	15.0	0.5	Braze
	4A	0.07	1200	17.0	2.9	Braze
	5A	0.08	1200	16.0	0.033	Braze

TABLE XI

1200 F CRUCIFORM HIGH CYCLE FATIGUE TEST RESULTS

RENE'95/CM50/U700 BRAZED JOINT

	Specimen	Stress (KSI)			Cycles	Failure
		Peak	Mean	Alternating	to Failure	Location
1200 F/Axial-Axial/A = 0.45[1]						
	1	12.9	8.9	4.0	0.010×10^6	U700
	2	6.4	4.4	2.0	14.8×10^6	(R.O.)
	3	12.9	8.9	4.0	2.6×10^6	U700
	4	19.3	13.3	6.0	2.7×10^6	U700
	5	25.8	17.8	8.0	0.03×10^6	U700
	6	9.6	6.6	3.0	12.8×10^6	(R.O.)
1200 F/Axial-Axial/A = 0.98[1]						
	1	24.2	12.1	11.9	60	Braze
	2	18.2	9.2	9.0	0.028×10^6	R95
	3	16.1	8.1	8.0	0.039×10^6	R95
	4	13.1	6.6	6.5	0.091×10^6	U700
	5	12.1	6.1	6.0	9.967×10^6	(R.O.)
	5	24.0	12.1	11.9	0.003×10^6	U700
	6	15.0	7.6	7.4	0.083×10^6	U700
	7	16.0	8.1	7.9	0.015×10^6	U700
	8	14.0	7.1	6.9	0.058×10^6	U700
	9	12.4	6.3	6.1	0.019×10^6	U700

1) Nominal braze gap is 0.003 inches
2) R.O. = "Run Out" or test discontinued with no failure occurring

TABLE XII

1400 F CRUCIFORM HIGH CYCLE FATIGUE TEST RESULTS

RENE' 95/CM50/U700 BRAZED JOINT

	Specimen	Stress (KSI) Peak	Mean	Alternating	Cycles to Failure	Failure Location
1400 F/Axial-Axial/A=0.98 (1	1	14.0	7.1	6.9	Failed on Loading	
	2	10.0	5.1	4.9	0.083×10^6	U700
	3	12.0	6.1	5.9	0.029×10^6	U700
	4	11.0	5.6	5.4	0.326×10^6	U700
	5	10.5	5.3	5.2	0.057×10^6	U700
	6	11.5	5.8	5.7	0.302×10^6	R'95
	7	11.5	5.8	5.7	1.718×10^6	U700
	8	12.2	6.2	6.0	0.007×10^6	U700
	9	4.18	2.1	2.08	7.00×10^6 (R.O)	(3
1400 F/Axial-Axial/A°0.98 (2	1	10.4	5.3	5.1	0.100×10^6	U700
	2	9.6	4.9	4.7	2.950×10^6	U700
	3	10.0	5.1	4.9	0.572×10^6	U700
	4	11.0	5.6	5.4	0.007×10^6	U700
	5	10.8	5.5	5.3	0.012×10^6	U700

1) Nominal braze gap is 0.003 inches
2) Nominal braze gap is 0.010 inches
3) R.O. = "Run Out" with no failure

TABLE XIII

U700 HIGH CYCLE FATIGUE TEST RESULTS

0.010" SHEET

1400 F/Axial-Axial/A=0.25

Specimen	Stress (KSI) Peak	Mean	Alternating	Cycles to Fatigue
1	100	80	20	6.216×10^6
2	150	120	30	0.017×10^6
3	125	100	25	1.244×10^6
4	115	92	23	2.701×10^6
5	95	76	19	10.395×10^6 (R.O.)[1]
6	100	80	20	9.016×10^6

1400 F/Axial-Axial/A=0.45

Specimen	Peak	Mean	Alternating	Cycles to Fatigue
1	96.6	66.6	30	15.315×10^6 (R.O.)
1	128.9	88.9	40	0.005×10^6
2	112.7	77.7	35	8.169×10^6
3	116.0	80	36	7.607×10^6
4	109.5	75.5	34	10.128×10^6 (R.O.)

1) R.O. is "Run Out" with no failure, specimen may then be step loaded to next stress level.

TABLE XIV

BRAZE AFFECTED U700 FATIGUE TEST RESULTS

1400 F A=0.45/AXIAL-AXIAL

0.010" SHEET

Specimen	Stress (KSI)			Cycles to Failure
	Peak	Mean	Alternating	
1	112.8	77.8	35.0	8.433×10^6
2	109.6	75.6	34.0	15.796×10^6
3	116.0	80.0	36.0	1.285×10^6
4	119.2	82.2	37.0	1.473×10^6
5	122.4	84.4	38.0	1.567×10^6
6	128.8	88.8	40.0	1.603×10^6
7	161.1	111.1	50.0	0.001×10^6
8	111.1	76.6	34.5	12.121×10^6

TABLE XV

RENÉ 95 TENSILE TEST RESULTS

Smooth Tensile Strength (TS), K_T=1.0

Specimen	Temperature (°F)	Ultimate Tensile Strength (KSI)	Average	NTS/TS
1	RT	227.9		
2	RT	231.2	228.0	
3	RT	224.8		
4	1000	221.9		
5	1000	— (Tab Failure)	220.4	
6	1000	219.0		
7	1200	202.8		
8	1200	205.0	203.3	
9	1200	202.1		
10	1300	174.6		
11	1300	178.4	177.6	
12	1300	179.7		
13	1400	150.4		
14	1400	155.1	151.7	
15	1400	149.6		

Notched Tensile Strength (NTS), K_T=3.0

Specimen	Temperature (°F)	Ultimate Tensile Strength (KSI)	Average	NTS/TS
1	RT	203.5		
2	RT	202.9	201.2	0.88
3	RT	197.1		
4	1200	194.9		
5	1200	191.7	193.2	0.95
6	1200	193.1		

TABLE XVI

RENE' 95 STRESS RUPTURE TEST RESULTS

Cooling Rate	Specimen	Temperature (°F)	Stress (KSI)	Time to Rupture (Hrs.)
2000-1800°F/10 Min.	1	1000	150	332.4 (R.O.)
	1	1200	150	6.6
	2	1000	180	292.7
	3	1000	205	6.5
	4	1200	135	44.9
	5	1200	125	122.5
	6	1200	130	42.3
	7	1300	100	64.0
	8	1300	95	95.8
	9	1300	90	188.2
	10	1400	55	108.8
	11	1400	60	95.4
	12	1400	58	90.9
2025-1800°F/22 Min.	1	1200	125	81.4
	2	1200	115	107.7
	3	1200	120	223.3

TABLE XVII

RENE' 95 FATIGUE TEST RESULTS

Axial-Axial, A=0.25

R.T.

Specimen	Stress (KSI) Peak	Mean	Alternating	Cycles to Failure
1	162.5	130.0	32.5	10.32×10^6 (R.O.)[1]
2	170.0	136.0	34.0	0.665×10^6
3	165.0	132.0	33.0	20.016×10^6
4	170.0	136.0	34.0	14.95×10^6 (R.O.)
4	200.0	160.0	40.0	0.193×10^6
5	175.0	140.0	35.0	0.743×10^6

1000°F

Specimen	Peak	Mean	Alternating	Cycles to Failure
1	195.0	156.0	39.0	4.480×10^6
2	190.0	152.0	38.0	10.350×10^6 (R.O.)
3	205.0	164.0	41.0	0.814×10^6
4	225.0	180.0	45.0	0.024×10^6
5	200.0	160.0	40.0	3.340×10^6
6	190.0	152.0	38.0	19.170×10^6 (R.O.)

1200°F

Specimen	Peak	Mean	Alternating	Cycles to Failure
1	205	164	41	0.105×10^6
2	200	160	40	0.628×10^6
3	195	156	39	0.45[illegible] $\times 10^6$
4	190	152	38	1.750×10^6
5	185	148	37	0.595×10^6
6	175	140	35	2.970×10^6

1) R.O. = "Run Out" with no failure

TABLE XVIII

RENE' 95 FATIGUE TEST RESULTS

Axial-Axial, A=0.45

R.T.

Specimen	Stress (KSI) Peak	Mean	Alternating	Cycles to Failure
1	154.7	106.7	48.0	0.415×10^6
2	135.3	93.3	42.0	19.9×10^6 (R.O.)[1]
3	112.8	77.8	35.0	14.2×10^6 (R.O.)
4	148.2	102.2	46.0	0.483×10^6
5	161.0	111.0	50.0	0.203×10^6
6	187.0	129.0	58.0	0.105×10^6

R.T/Notched, $K_T = 3.0$

Specimen	Peak	Mean	Alternating	Cycles to Failure
1	83.8	57.5	26.0	0.202×10^6
2	96.6	66.6	30.0	0.103×10^6
3	56.4	38.9	17.5	19.0×10^6 (R.O.)
3	74.1	51.1	23.0	0.616×10^6
4	128.9	89.0	40.0	0.032×10^6
5	48.3	33.3	15.0	10.380×10^6 (R.O.)
6	64.5	44.5	20.0	0.830×10^6

1) R.O. = "Run Out" with no failure

TABLE XIX

RENE' 95 FATIGUE TEST RESULTS

Reversed Bending, A =∞

Specimen	Stress (KSI) Peak	Mean	Alternating	Cycles to Failure
R.T.				
1	80.9	0	80.9	1.62×10^6
2	71.6	0	71.6	0.588×10^6 (1
3	82.1	0	82.1	0.969×10^6
4	82.3	0	82.3	0.969×10^6
5	66.6	0	66.6	3.615×10^6
6	72.6	0	72.6	1.724×10^6
7	60.0	0	60.0	12.756×10^6 (2,3 (R.O.)
8	73.2	0	73.2	2.447×10^6
9	62.0	0	62.0	6.979×10^6
1000°F				
1	60.0	0	60.0	10.345×10^6 (R.O.)
1	75.0	0	75.0	4.4×10^6
2	60.2	0	60.2	5.889×10^6 (4
3	85.0	0	85.0	10.051×10^6 (R.O.)
3	100.0	0	100.0	0.077×10^6
4	78.0	0	78.0	17.481×10^6 (R.O.)
5	96.0	0	96.0	2.7×10^6 (5
6	102.2	0	102.2	1.664×10^6
1200°F				
1	90.0	0	90.0	11.642×10^6 (R.O.)
1	115.0	0	115.0	0.016×10^6
2	104.7	0	104.7	0.335×10^6
3	98.1	0	98.1	8.433×10^6
4	97.0	0	97.0	0.054×10^6 (6

1) Failed shim, rerun
2) Later retested as specimen #5, 1000°F, A=∞
3) R.O. = "Run Out" with no failure
4) T.C. Failure
5) Originally tested as specimen #7, RT, A=∞
6) Reached 1350°F before loading

TABLE XX

RENE' 95 FATIGUE RETEST RESULTS

R.T./Reversed Bending/A=∞

Retest: Rounded and polished edges
Shot peened edges and tabs
2025 F/22 Min. cool

Specimen	Stress (KSI) Peak	Mean	Alternating	Cycles to Failure
1	65.0	0	65.0	17.195×10^6 (R.O.)[1]
2	66.3	0	66.3	1.826×10^6
3	70.8	0	70.8	1.965×10^6
4	65.4	0	65.4	3.860×10^6
5	64.9	0	64.9	2.891×10^6
6	67.0	0	67.0	2.302×10^6

R.T./Axial-Axial/A = 0.45

Retest: 2025 F/22 Min. Cool

Specimen	Peak	Mean	Alternating	Cycles to Failure
1	145.0	100.0	45.0	0.447×10^6
2	128.8	88.8	40.0	13.3×10^6 (R.O.)
3	138.5	95.5	43.0	0.618×10^6
4	132.1	91.1	41.0	11.1×10^6 (R.O.)

1) R.O. = test "Run Out" or test discontinued with no failure occurring

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TABLE XXI

MICROSTRUCTURAL EFFECTS ON R'95 PROPERTIES

Material State	RT Tensile UTS KSI	RT Tensile 0.2 YLD KSI	RT Tensile Elong. -%	RT Tensile R.A. -%	1200F Tensile UTS KSI	1200F Tensile 0.2 YLD -KSI	1200F Tensile Elong. -%	1200F Tensile R.A. -%	1200F 150 KSI Rupture -Hours	1200F 150 KSI Rupture %RA
Specification:										
Class B	230	186	10	15	207	172	10	15	50	5
Class C	220	174	10	15	197	161	10	15	50	5
Class D	208	166	10	15	186	153	10	15	50	5
Typical Duplex	235	191	15	18	212	178	15	16	110	10-15
Fine Grained	235.5	178.7	19.4	21	217	170	11.7	13	215	4.8
									301	5.0
									234	5.6
									305	5.8
After Braze Heat Treat										
Duplex					197	152	19	24.2	34.7	26.8
					198	155	18.2	25.1	22.1	26.8
Fine Brained					194	145	13.3	15.6	6.9	7.8
					192	146	13.0	11.2	9.2	11.4

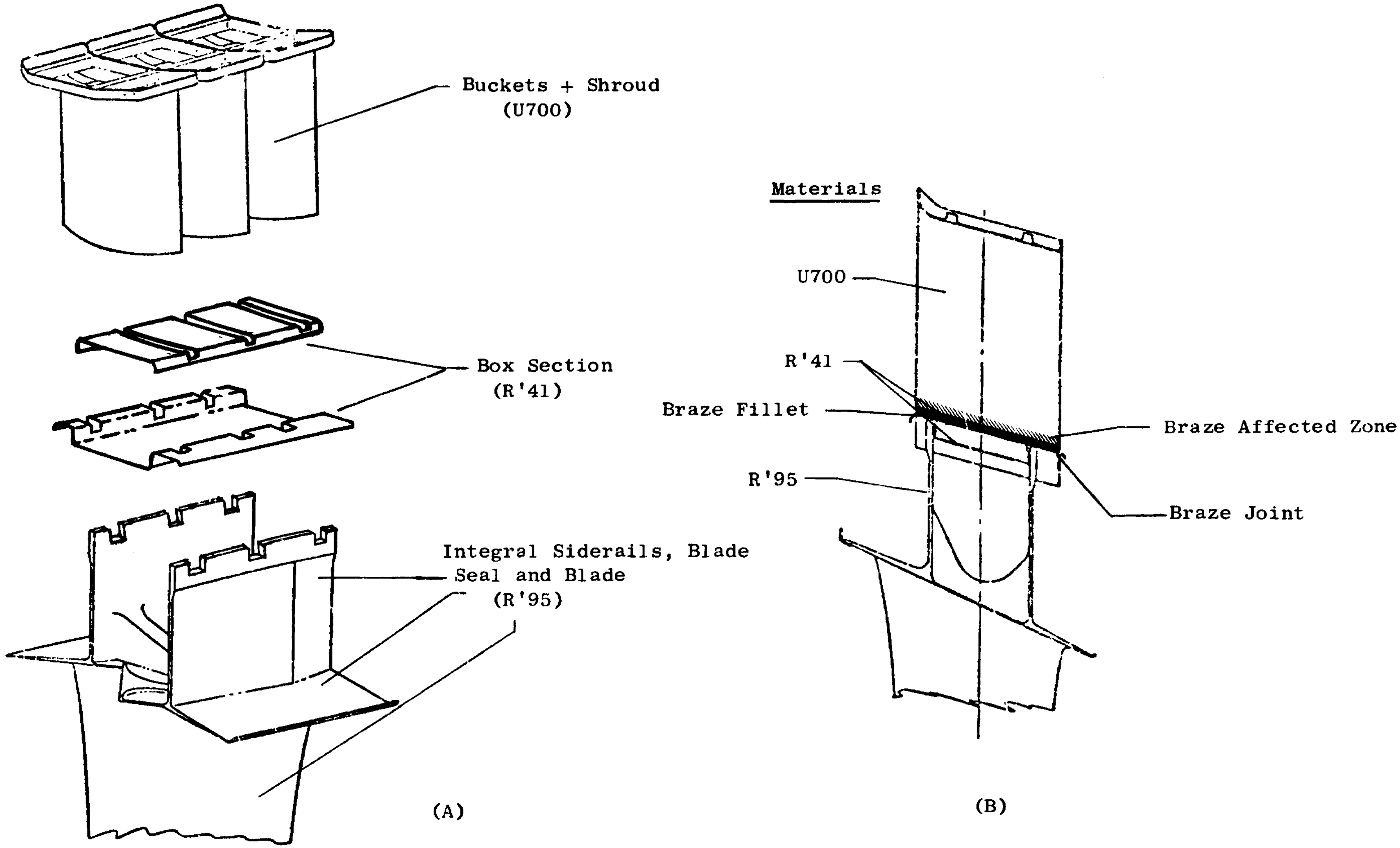


Figure 1. Full Scale LF460 Blade/Turbine Structure

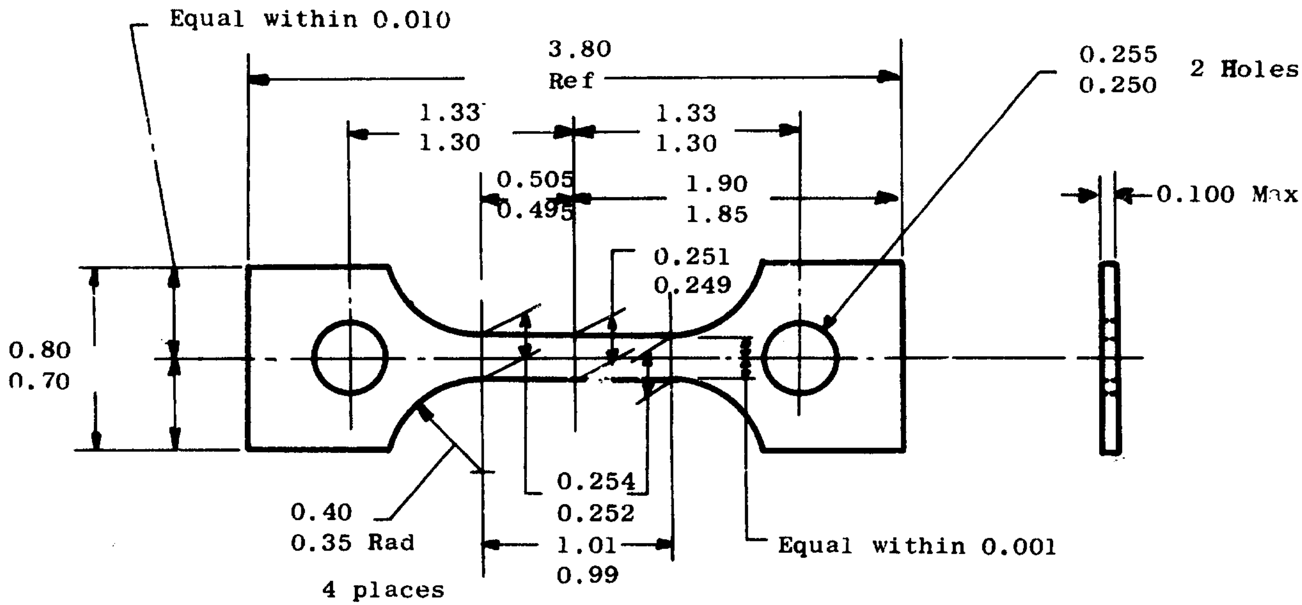


Figure 2. Sheet Specimen - R' 95 Parent Metal Smooth Tensile and Stress Rupture

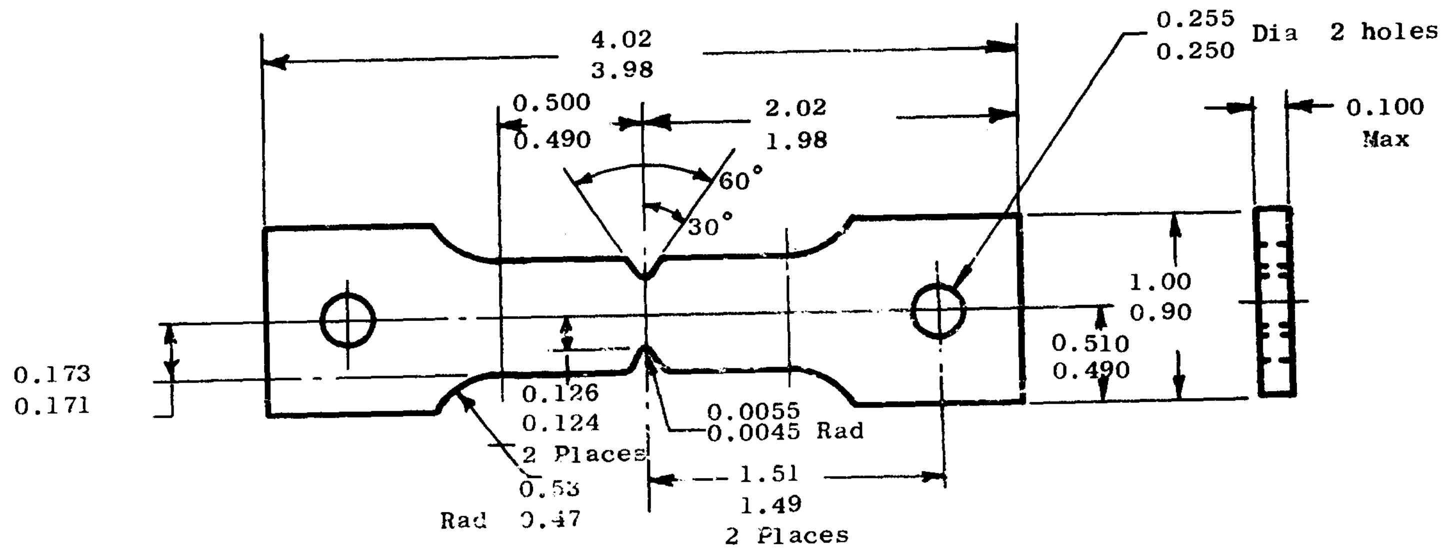


Figure 3. Sheet Specimen - R' 95 Parent Metal
Notch Tensile

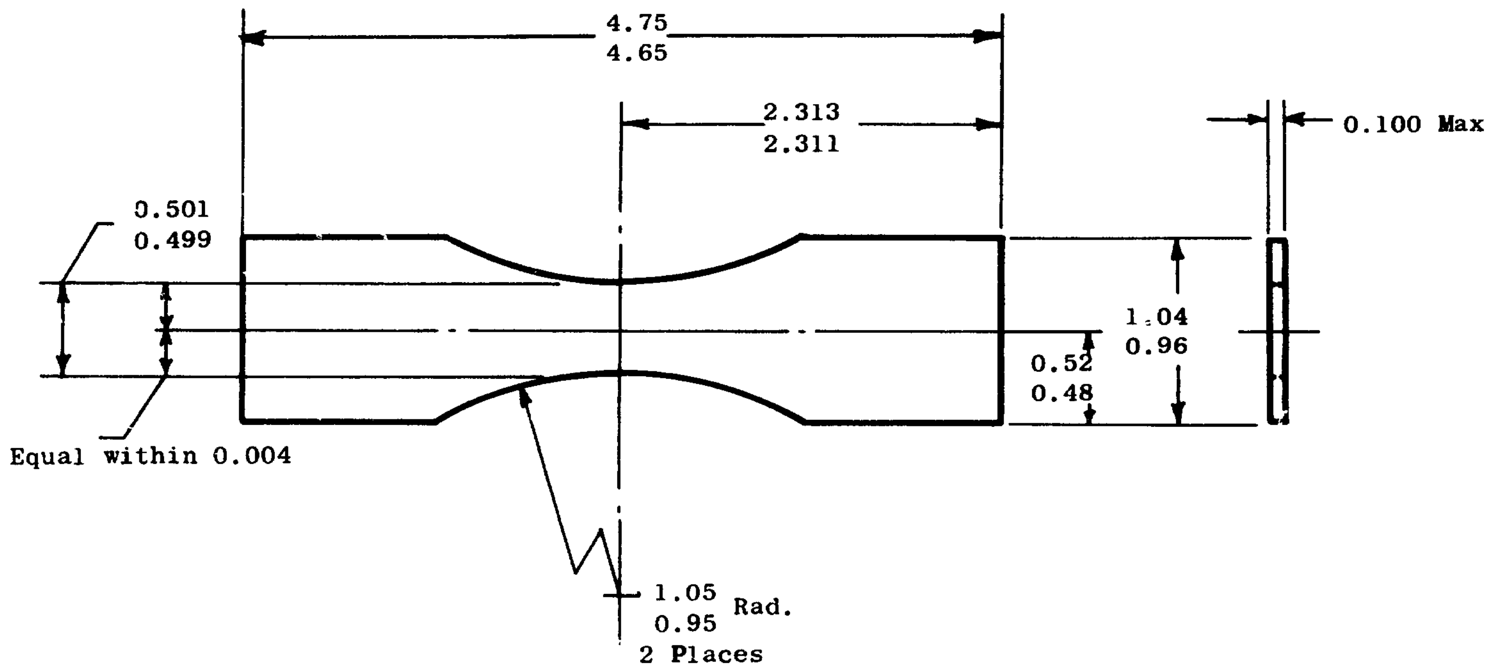


Figure 4. Sheet Specimen - R' 95 Parent Metal
Bending Fatigue

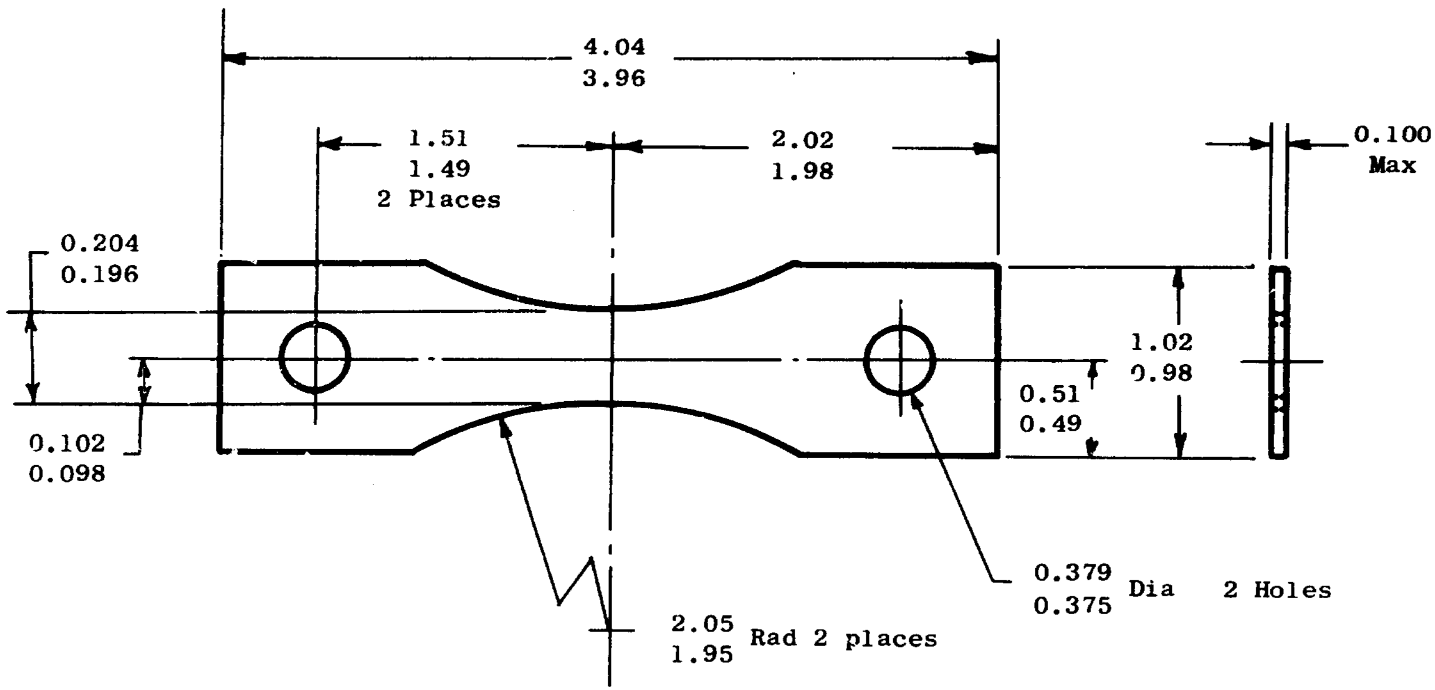


Figure 5. Sheet Specimen - R' 95 Parent Metal Axial/Axial Fatigue

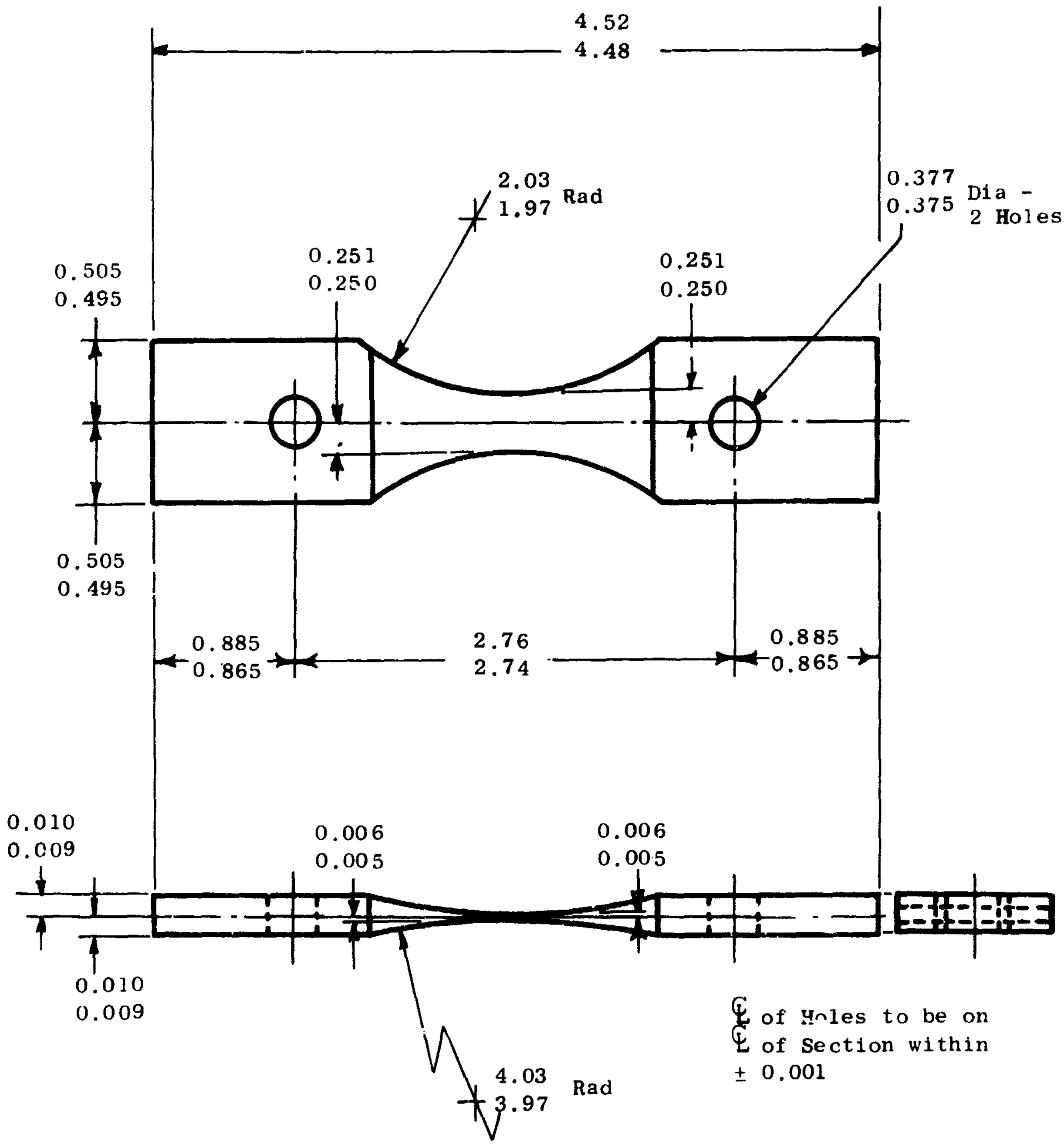


Figure 6. Plate Specimen - Udimet 700 Parent Metal
Combined Fatigue, Axial/Axial Mode

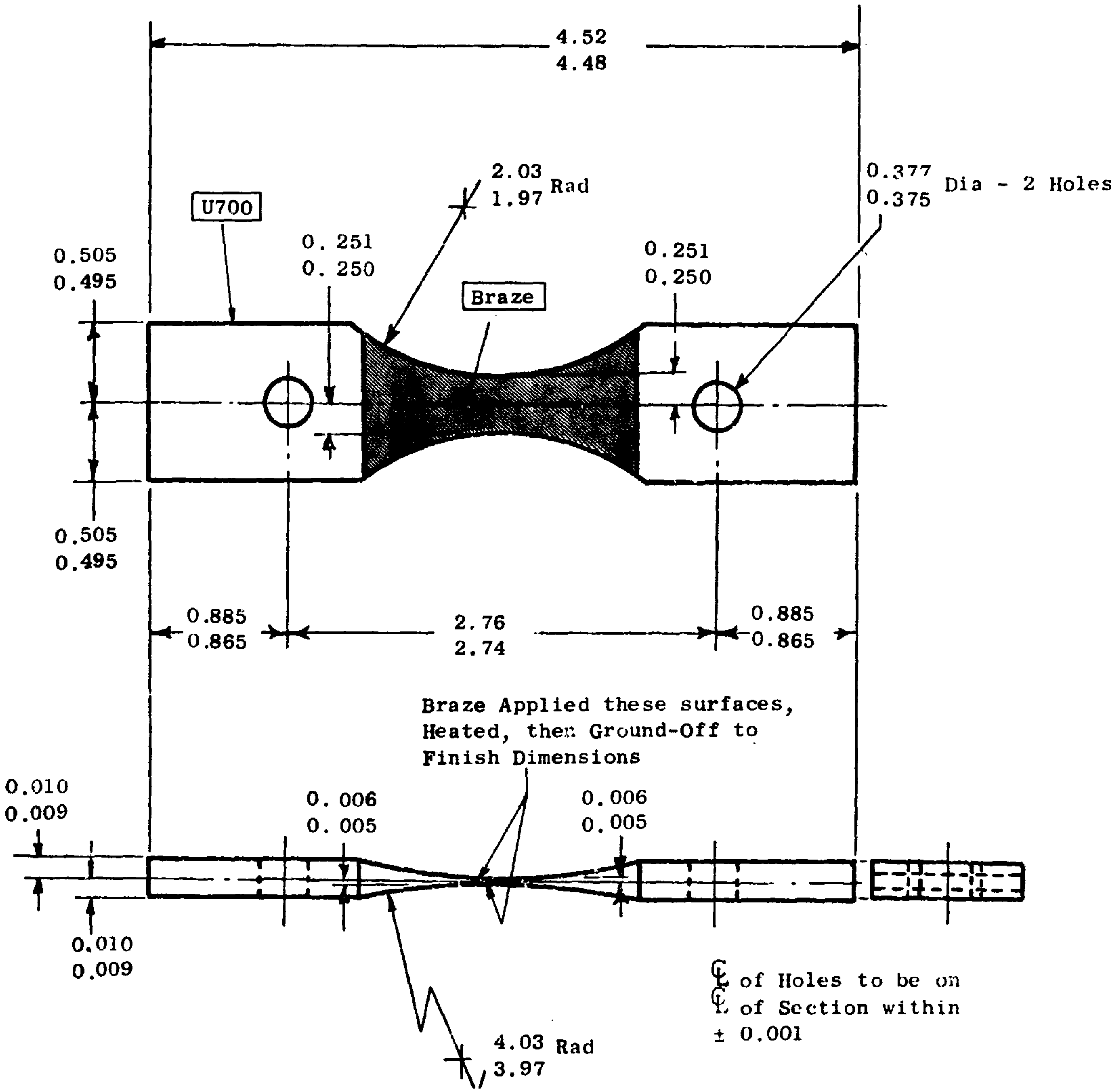
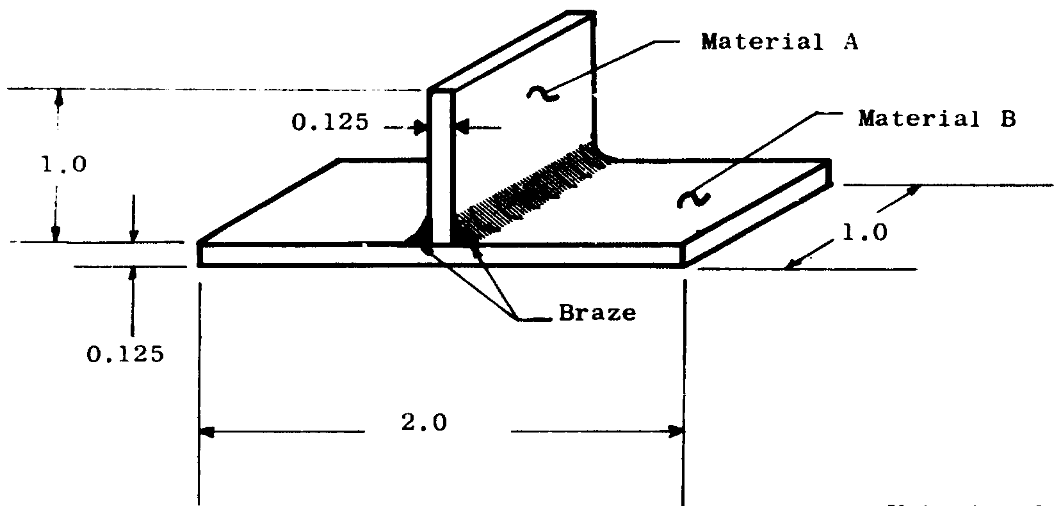


Figure 7. Braze Coated U700 Fatigue Specimen



Material Combinations

Specimen	Materials A	Materials B
1	U700	R'95
2	R'41	R'95
3	U700	R'41

Figure 8. "T" Joint Braze Specimen

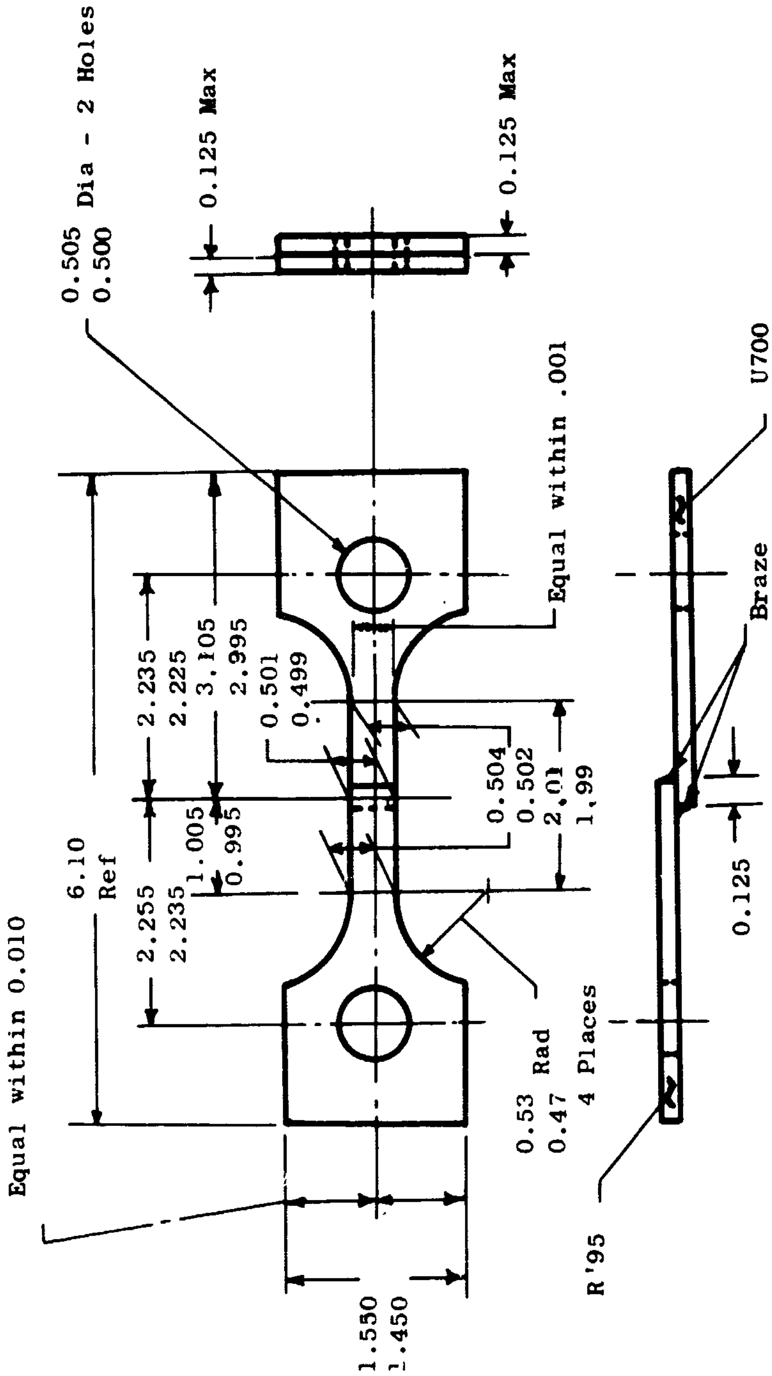


Figure 9. "1t" Overlap Joint Braze Specimen

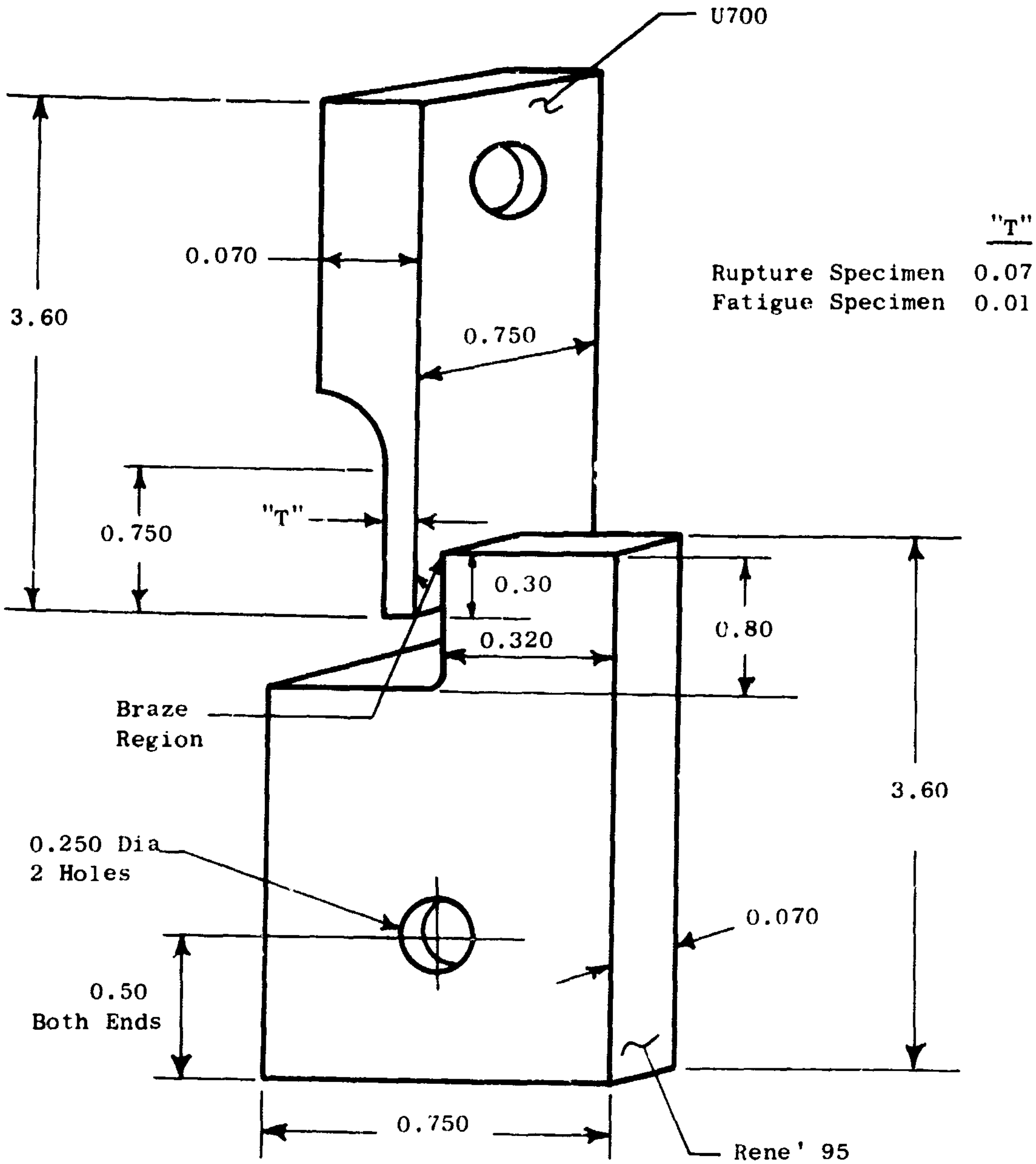


Figure 10. Simulated Braze Joint Specimen (Cruciform) for Rupture and Combined Stress Fatigue Evaluation

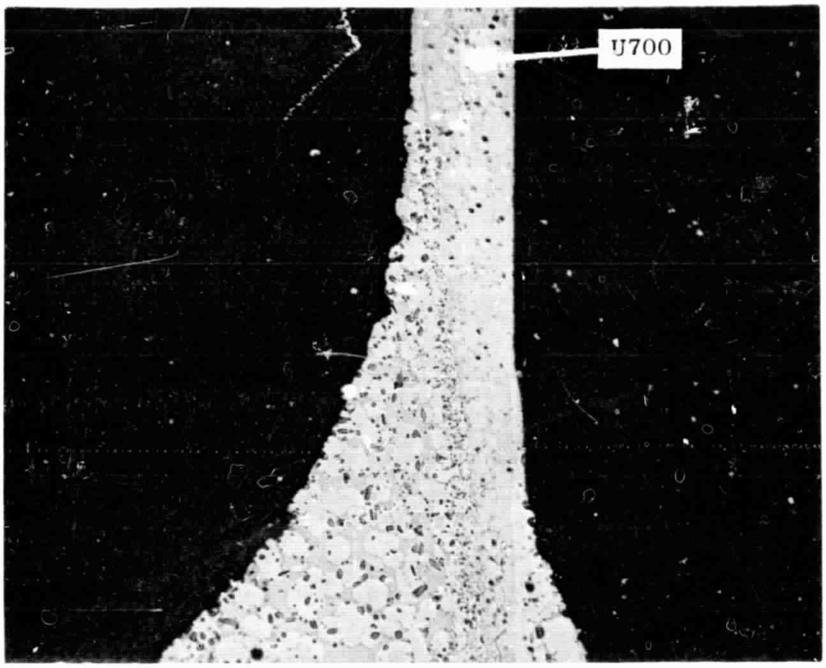


Figure 11 "T" Joint: Ni Plated 0.01 U700/B84/0.10 R'95
2025 F/10 Minutes, 50X (Upper Portion)

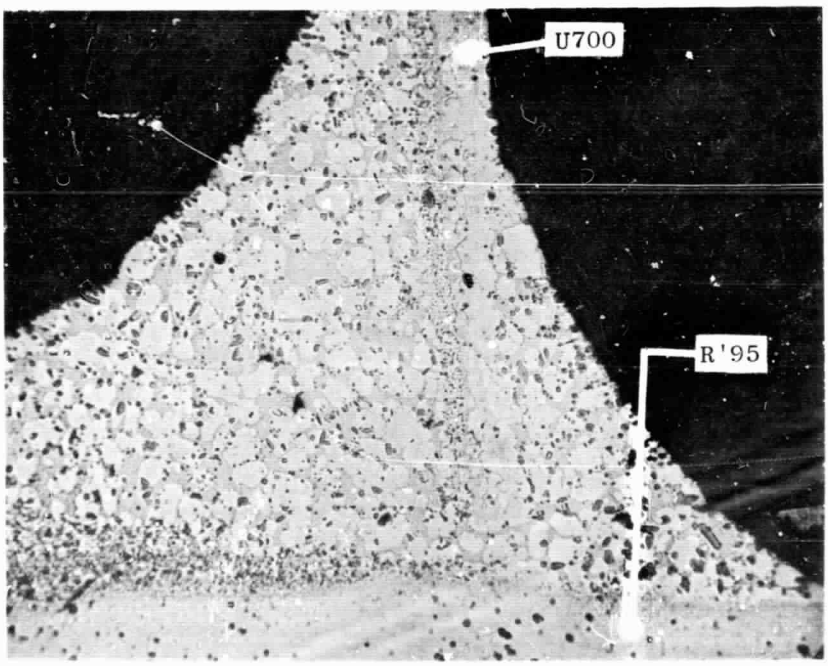


Figure 12 "T" Joint: Ni Plated 0.01 U700/B84/0.10 R'95
2025 F/10 Minutes, 50X (Lower Portion)

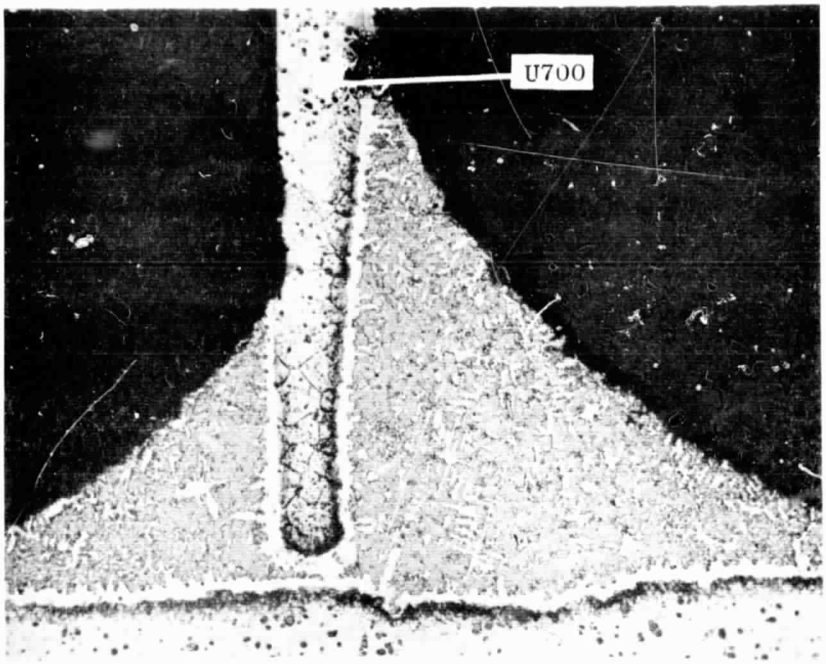


Figure 13 "T" Joint: 0.01 U700/CM53/0.1 R'95
2025 F/10 Minutes, 50X

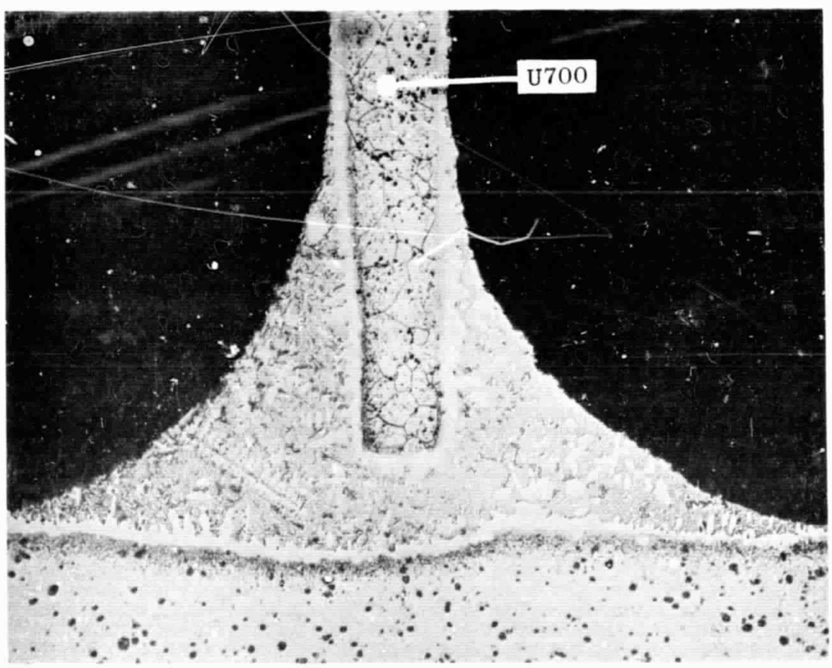


Figure 14 "T" Joint: Ni Plated 0.01 U700/CM53/0.10 R'95
2025 F/10 Minutes, 50X

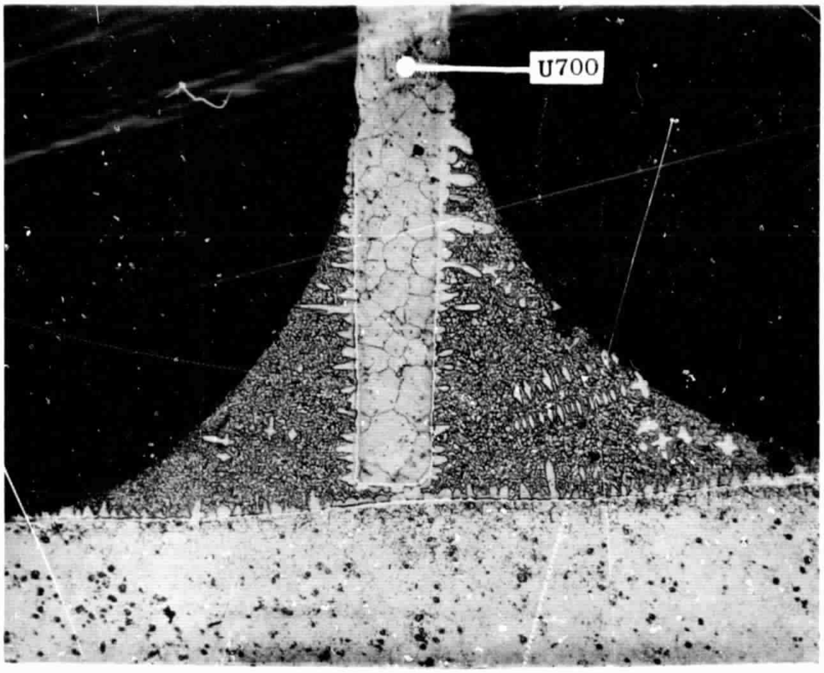


Figure 15 "T" Joint: 0.01 U700/CM50/0.10 R'95
2025 F/10 Minutes, 50X

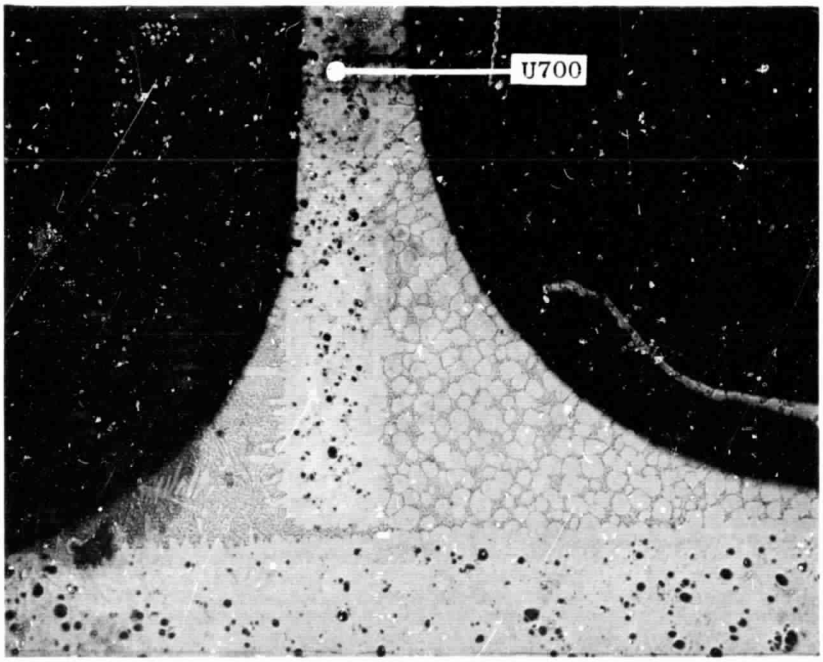


Figure 16 "T" Joint: Ni Plated 0.01 U700/CM50/0.10 R'95
2025 F/10 Minutes, 50X

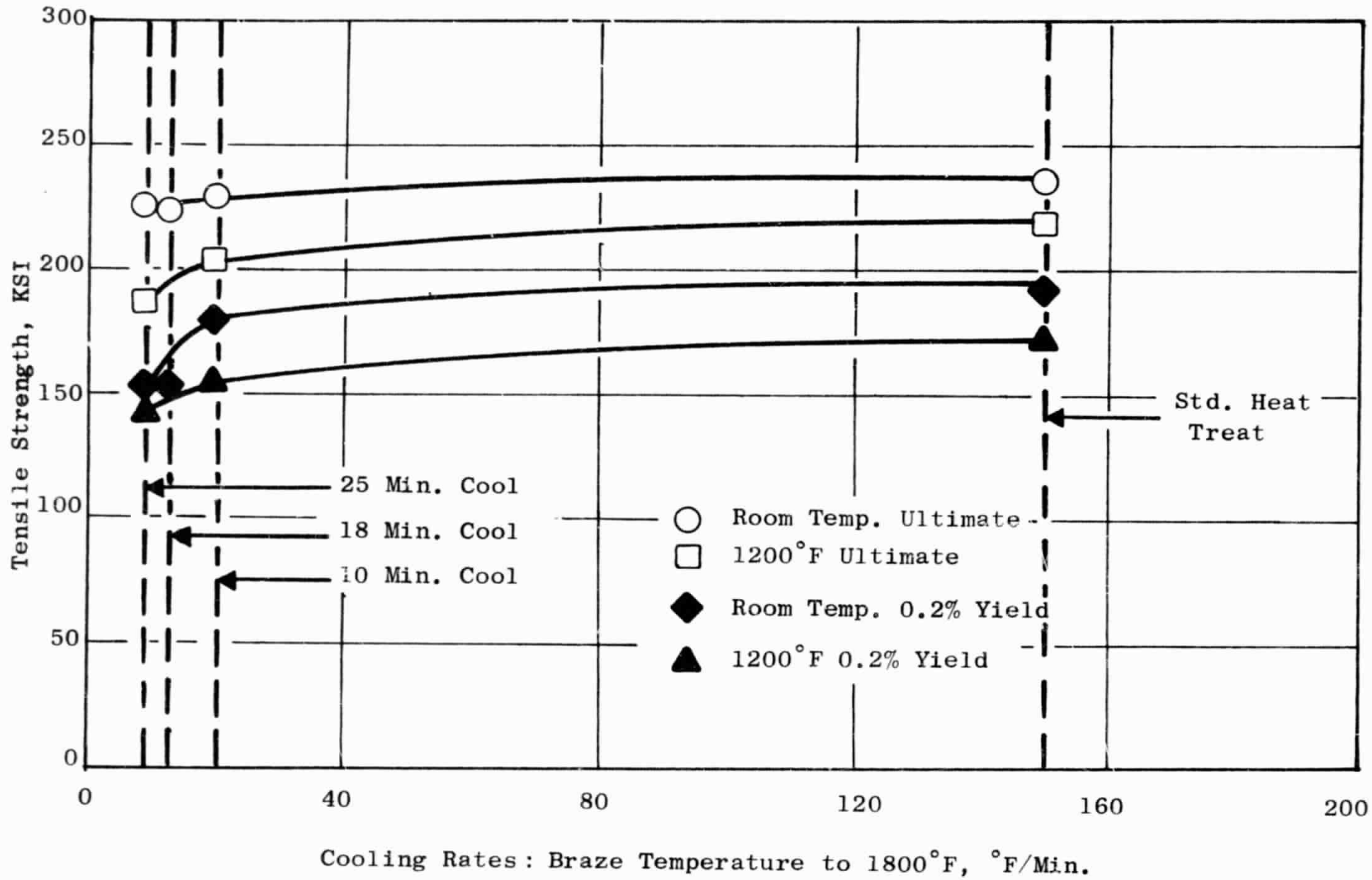


FIGURE 17. EFFECT OF COOLING RATE ON RENÉ 95 TENSILE STRENGTHS

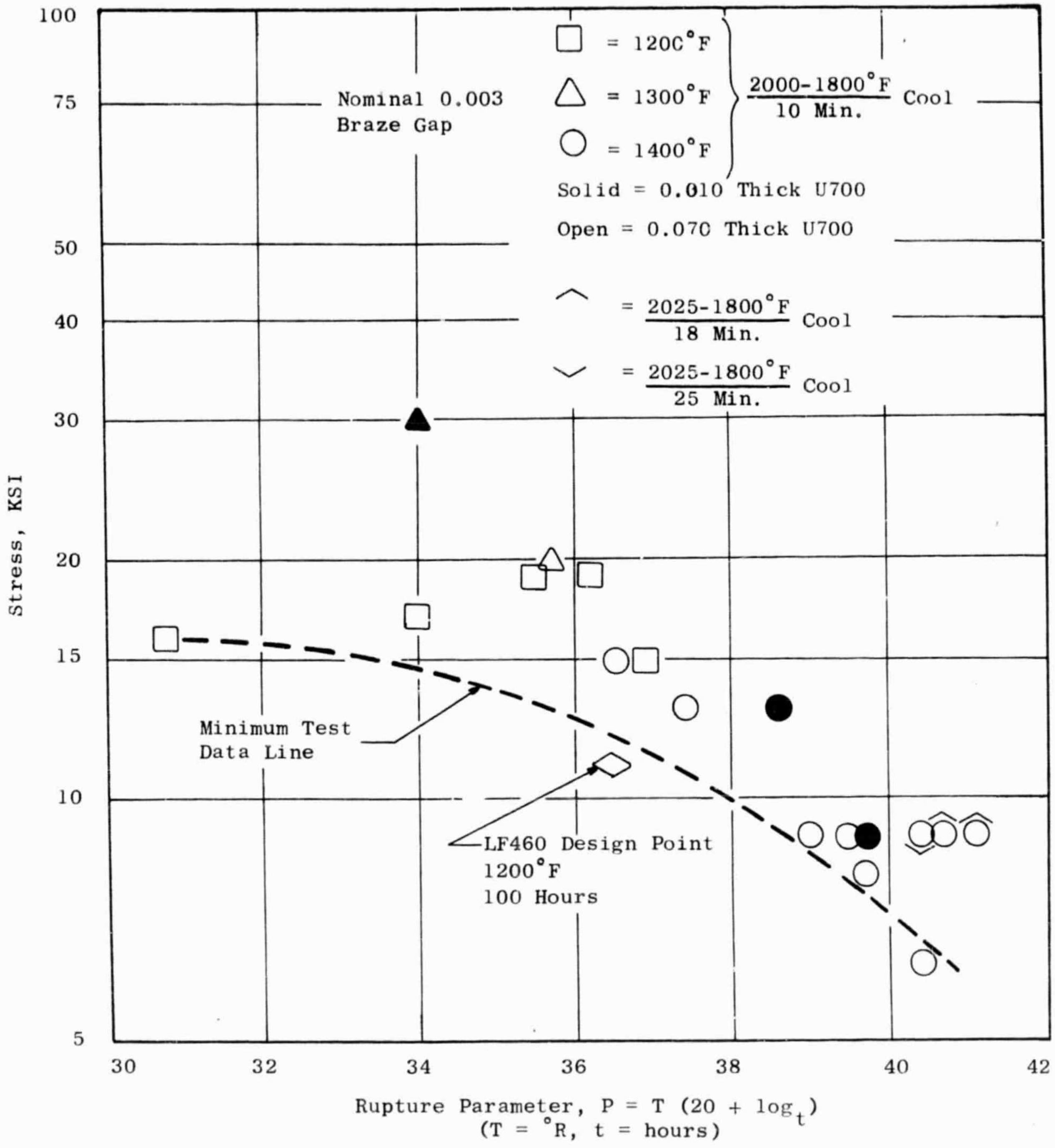


Figure 18. Cooling Rate Effect on Cruciform Rupture Strength R'95/CM50/U700 Brazed Joint

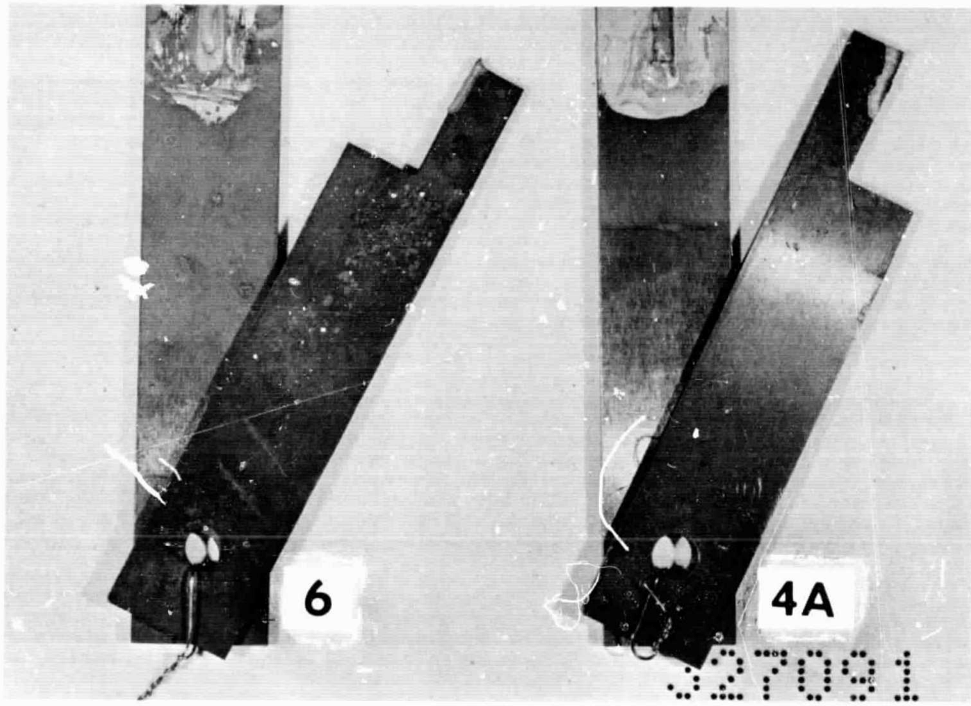


Figure 19 Braze Failure Surfaces
Cruciform Rupture Test Specimens
U700 Plan View, R'95 Side View

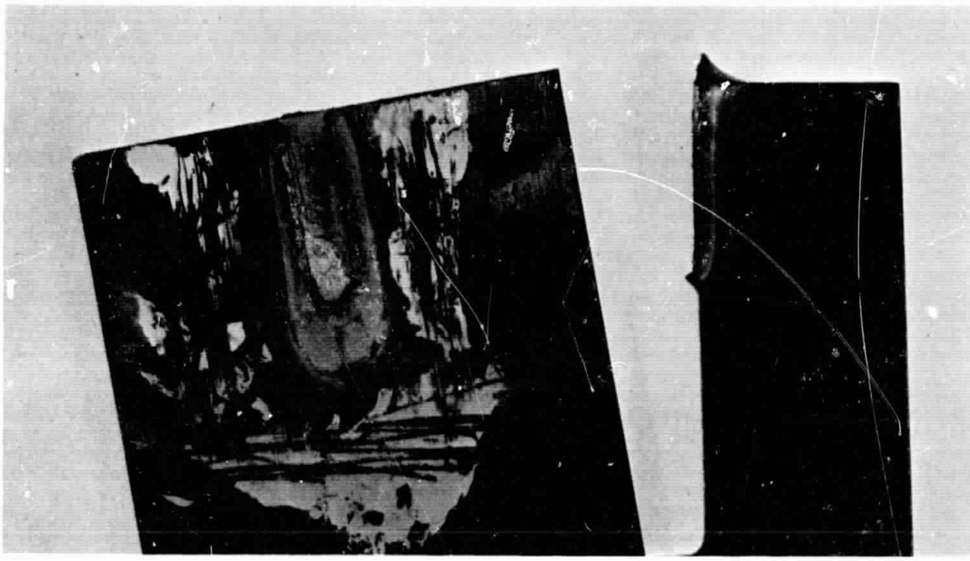


Figure 20 Braze Failure Surface, 4X Closeup
Cruciform Rupture Test Specimen #6
U700 Plan View, R'95 Side View

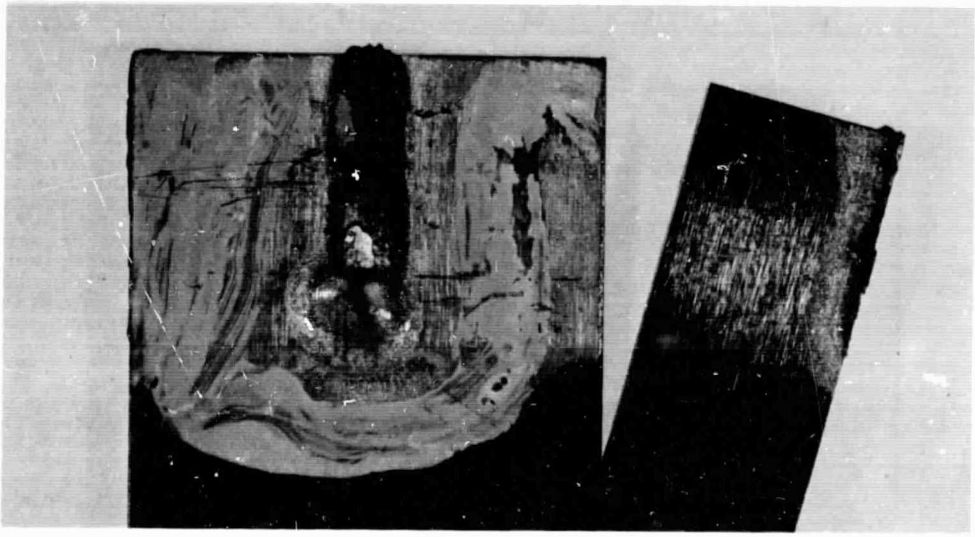


Figure 21 Braze Failure Surface, 4X Closeup
Cruciform Rupture Test Specimen #4A
U700 Plan View, R'95 Side View

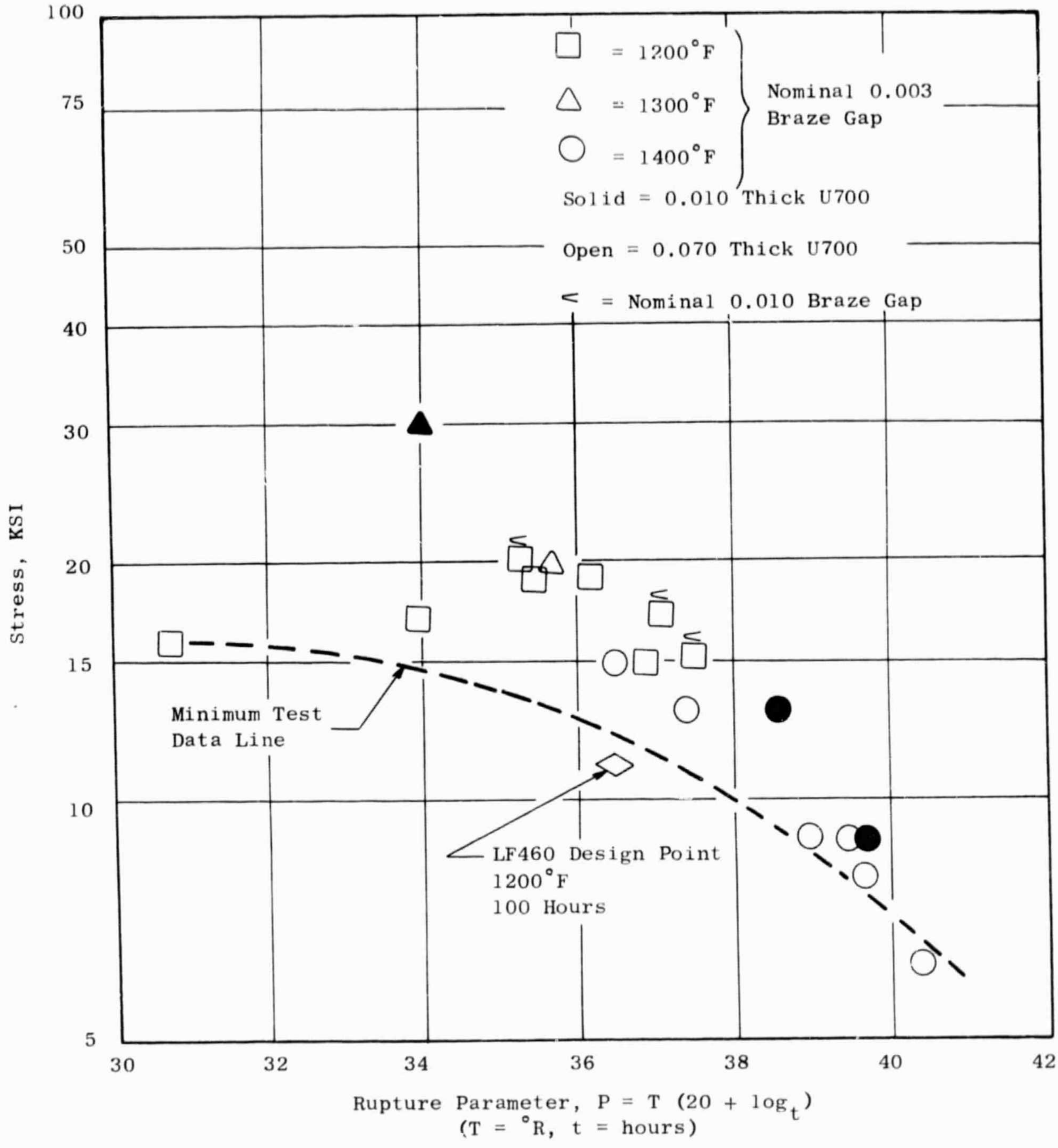


Figure 22. Effect of 0.010 Braze Gap on Cruciform Rupture Strength R'95/CM50/U700 Brazed Joint

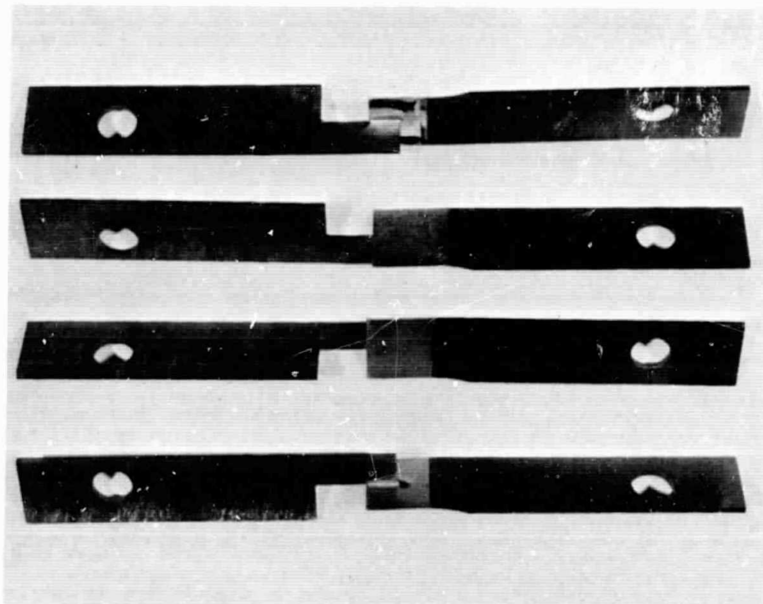


Figure 23 Cruciform Fatigue Test Specimens

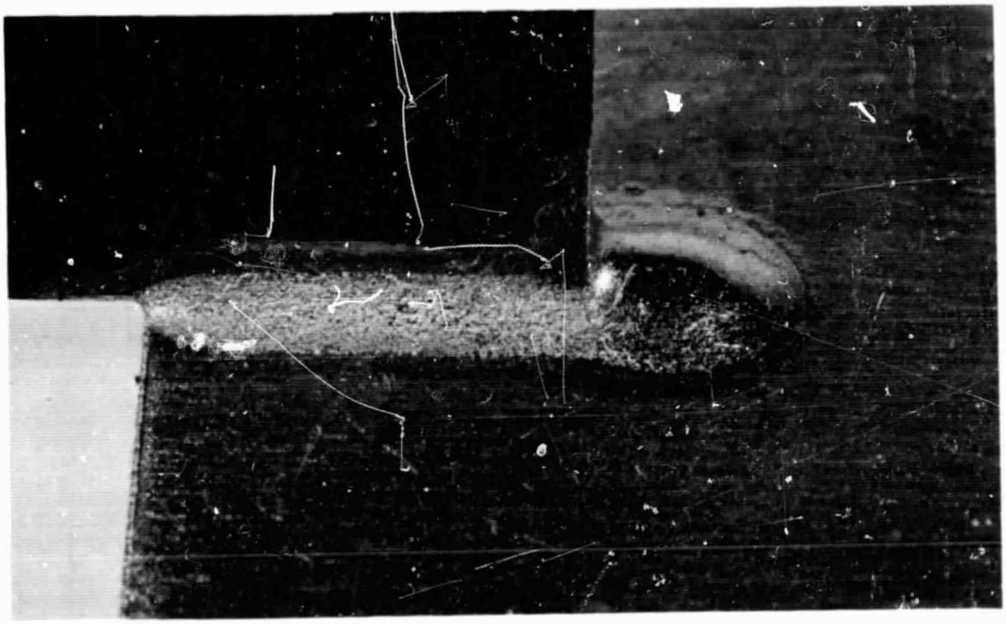


Figure 24 Braze Surface, 10X Closeup
Cruciform Fatigue Test Specimen #5
0.010 Inch Gap, 1400 F

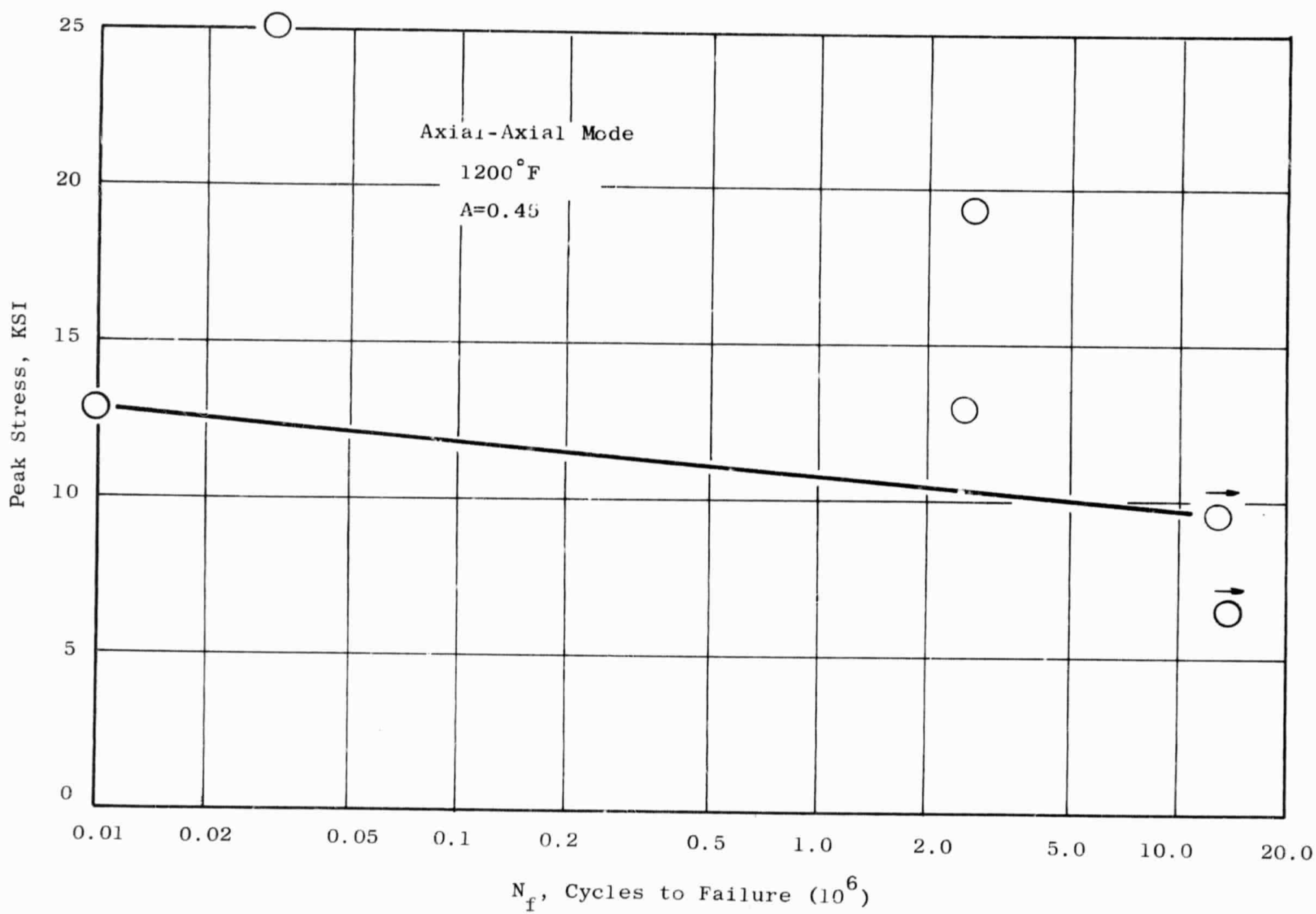


Figure 25. Cruciform High Cycle Fatigue: R'95/CM50/U700 Braze Joint

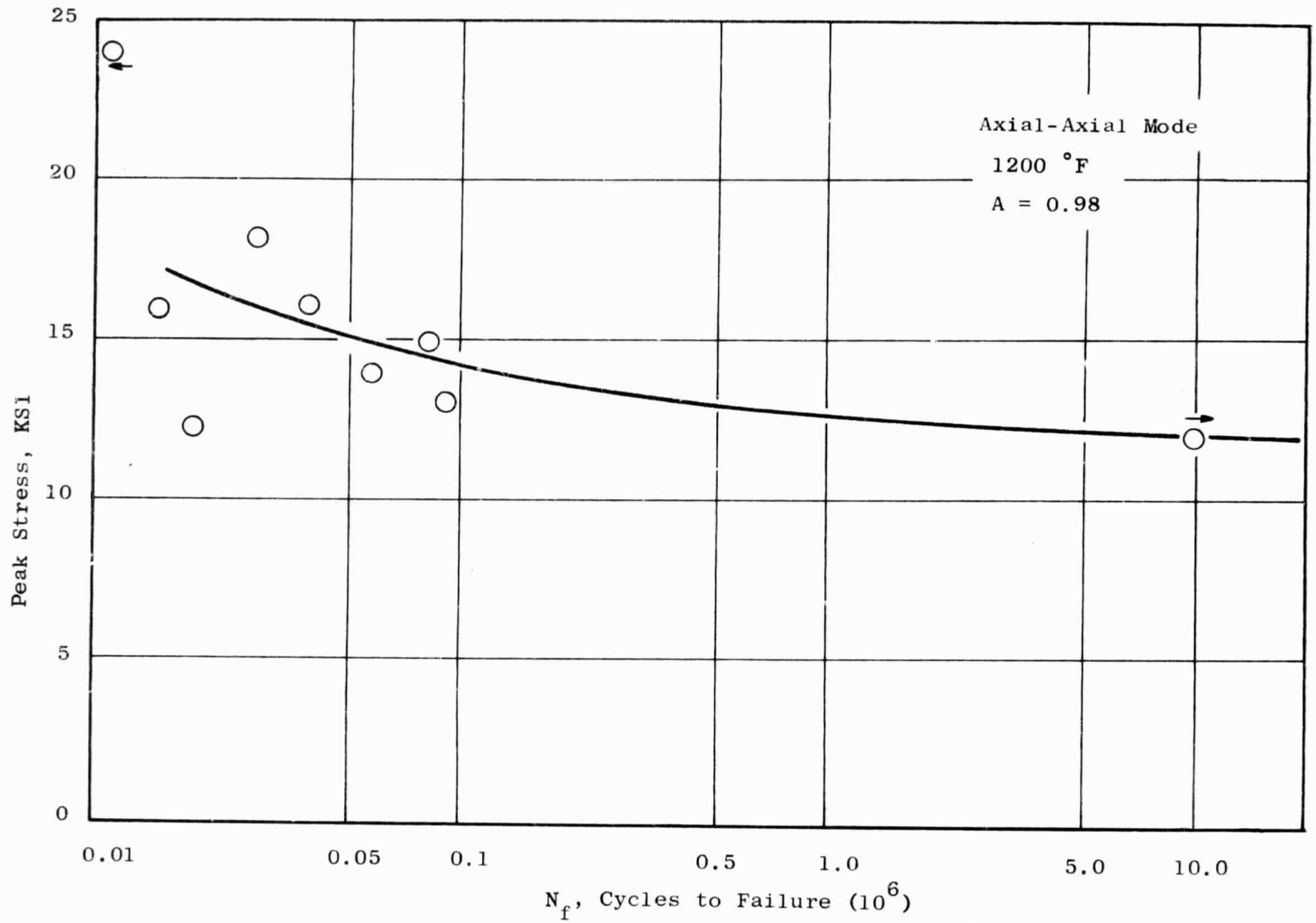


Figure 26. Cruciform High Cycle Fatigue: R'95/CM50/U700 Brazed Joint

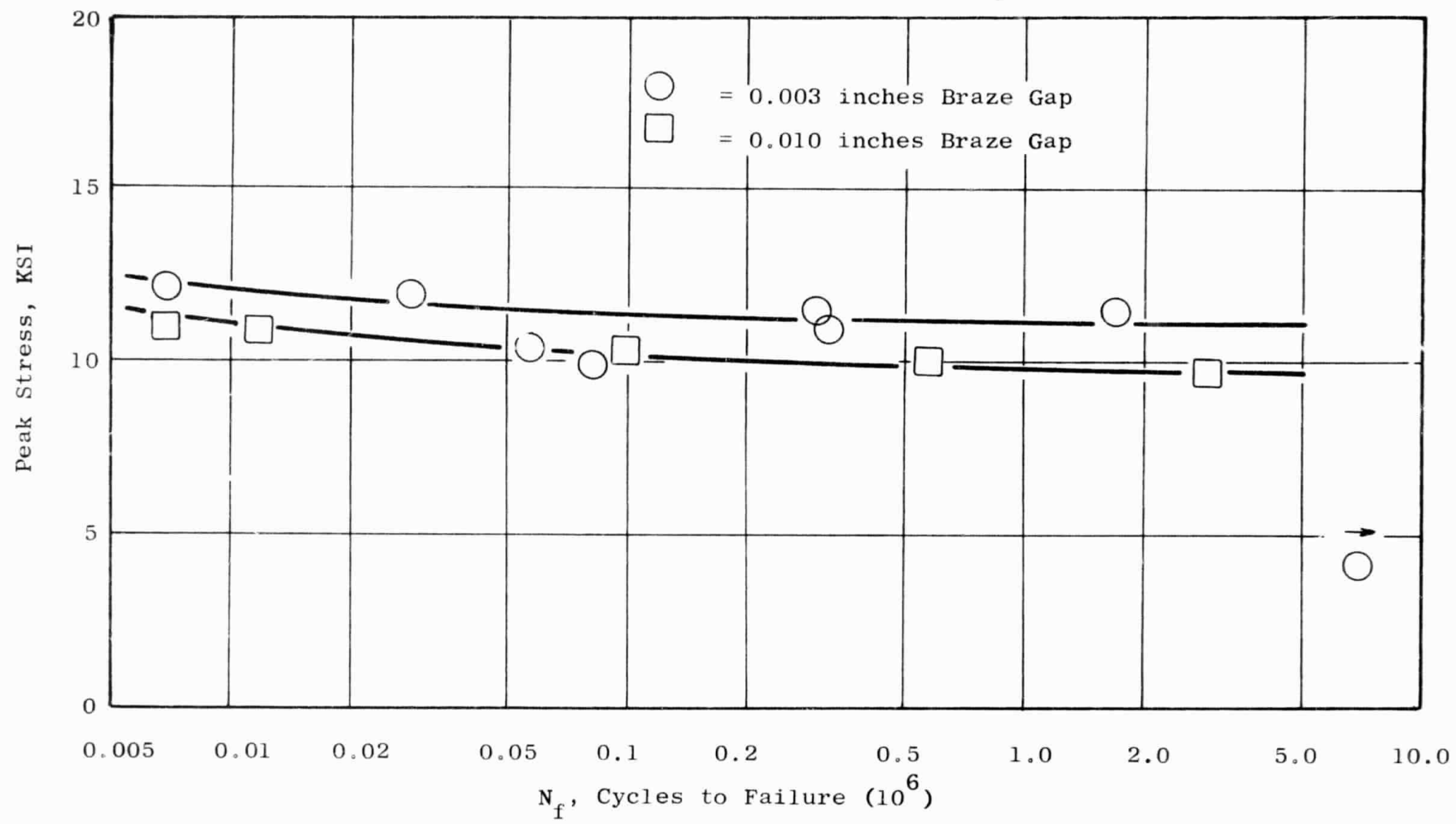


Figure 27. Braze Gap Effects on Cruciform High Cycle Fatigue R'95/CM50/U700 Brazed Joint, 1400°F, A = 0.98

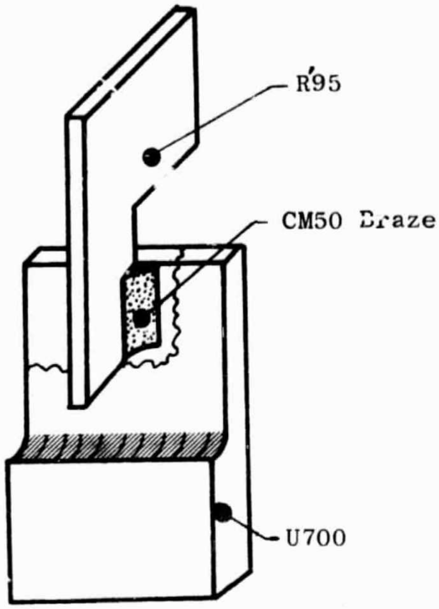


Figure A - U700 Failure

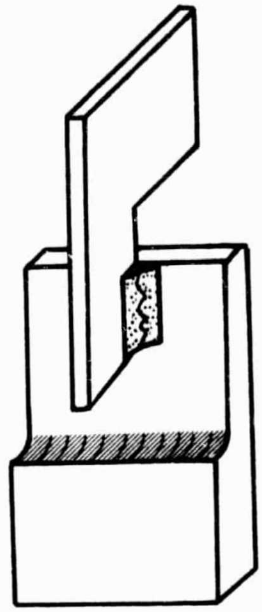


Figure B - CM50 Braze Failure

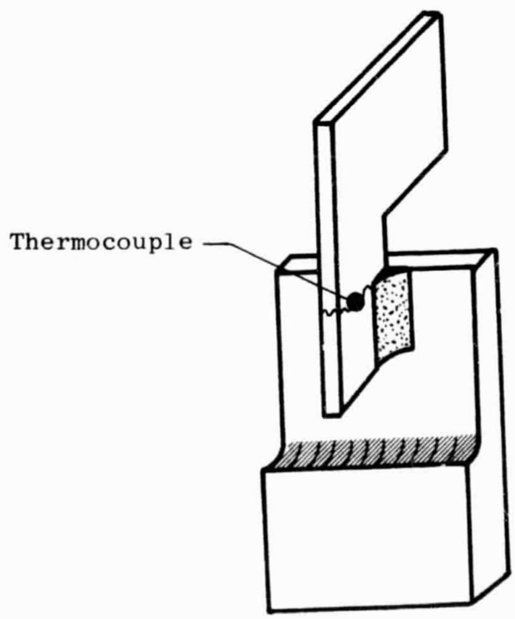


Figure C - R'95 Failure

Figure 28. Fatigue Failure Locations of R'95/CM50/U700 Brazed Cruciform Joint

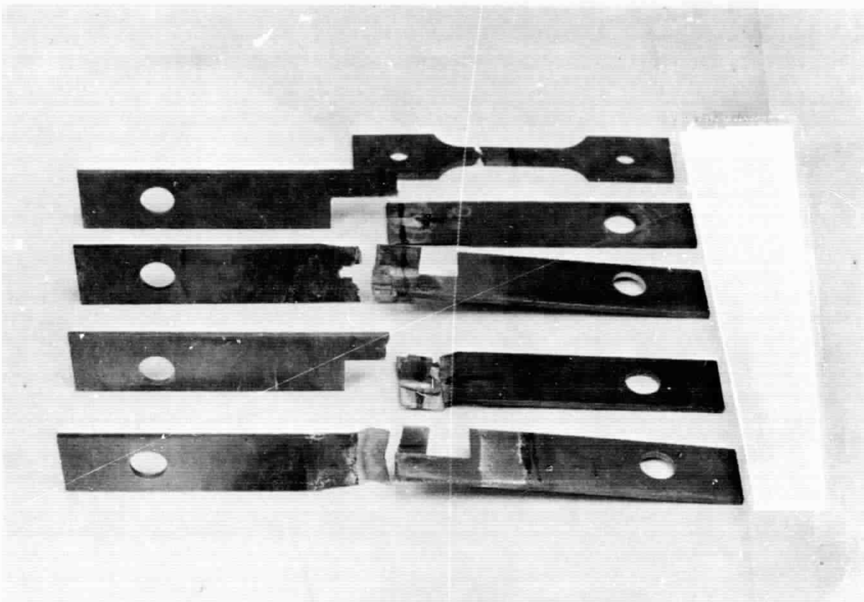


Figure 29 Failed Test Specimens

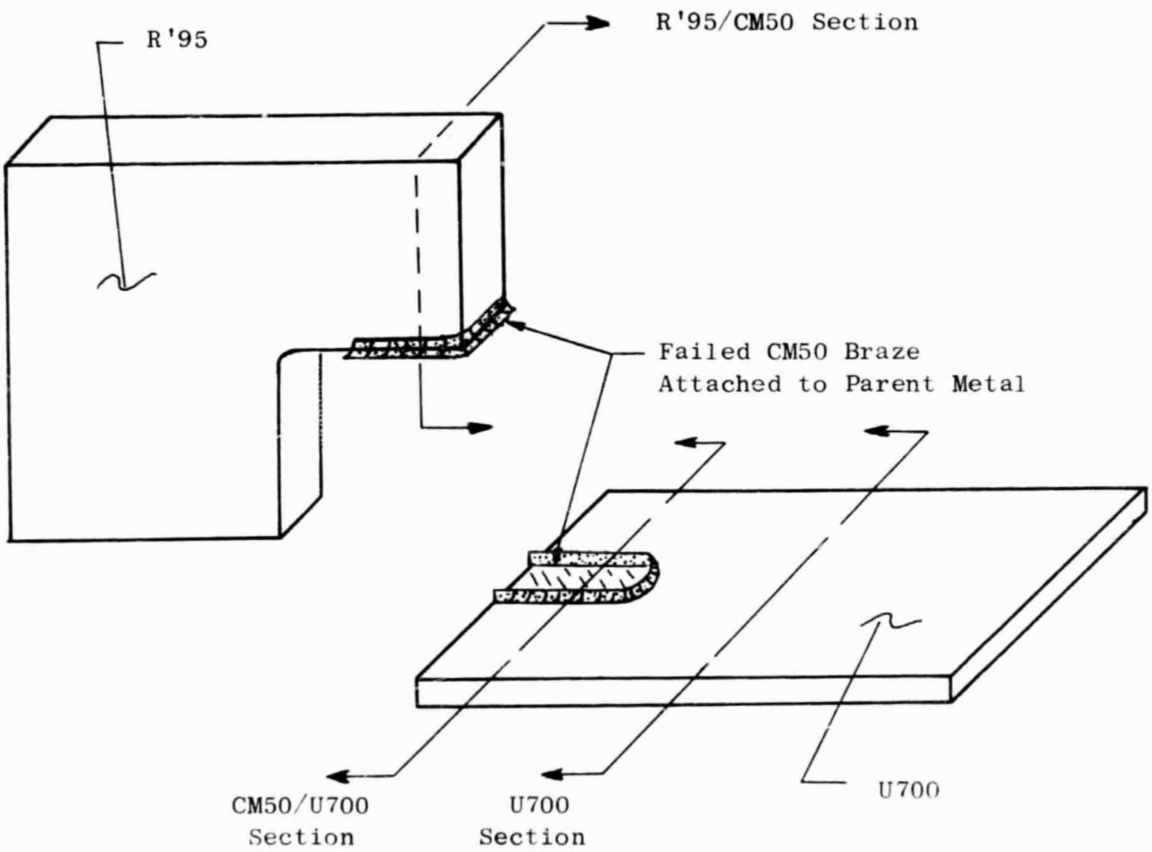


Figure 30. Micro Section Locations Cruciform Stress Rupture Specimen Case #3 (Cooling Effect)

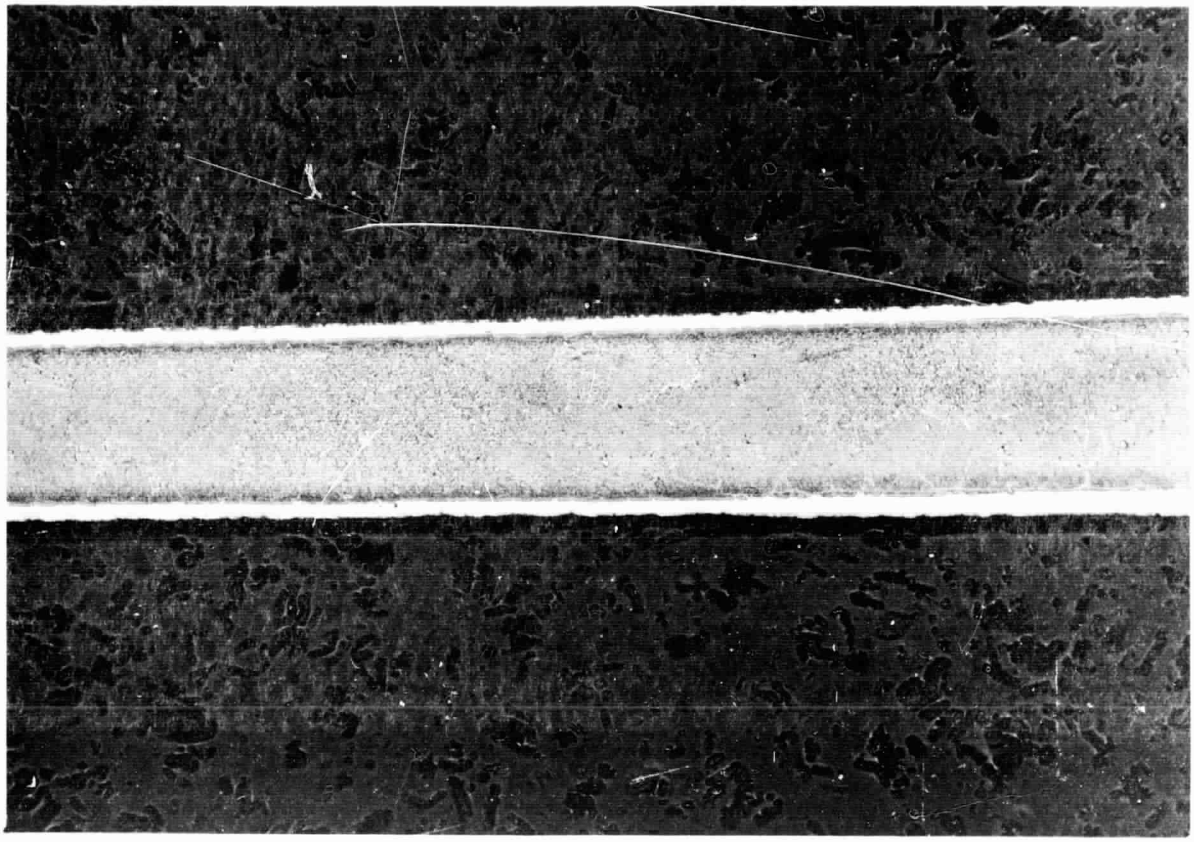


Figure 31 Section Through U700
Cruciform Stress Rupture Specimen #3 (Cooling Effect)
Failed in CM50, 100X

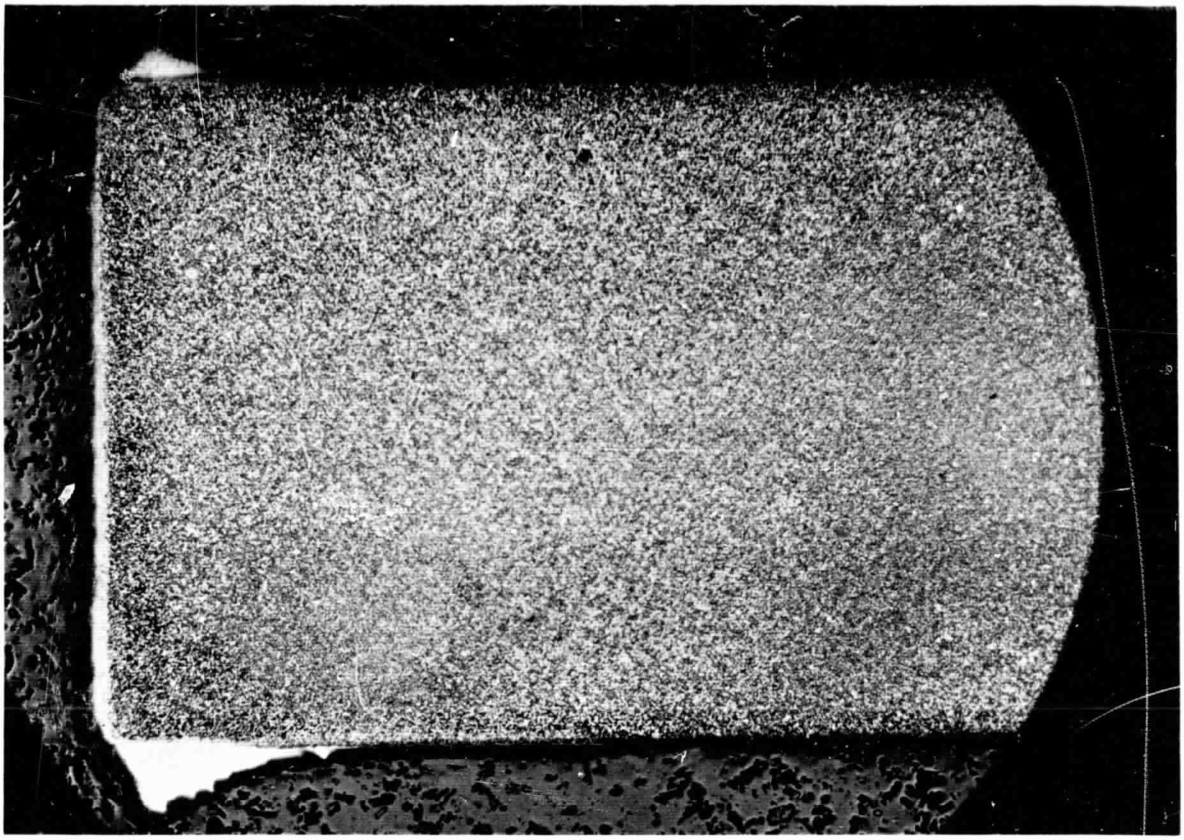


Figure 32 Section Through R'95/CM50
Cruciform Stress Rupture Specimen #3 (Cooling Effect)
Failed in CM50, 50X

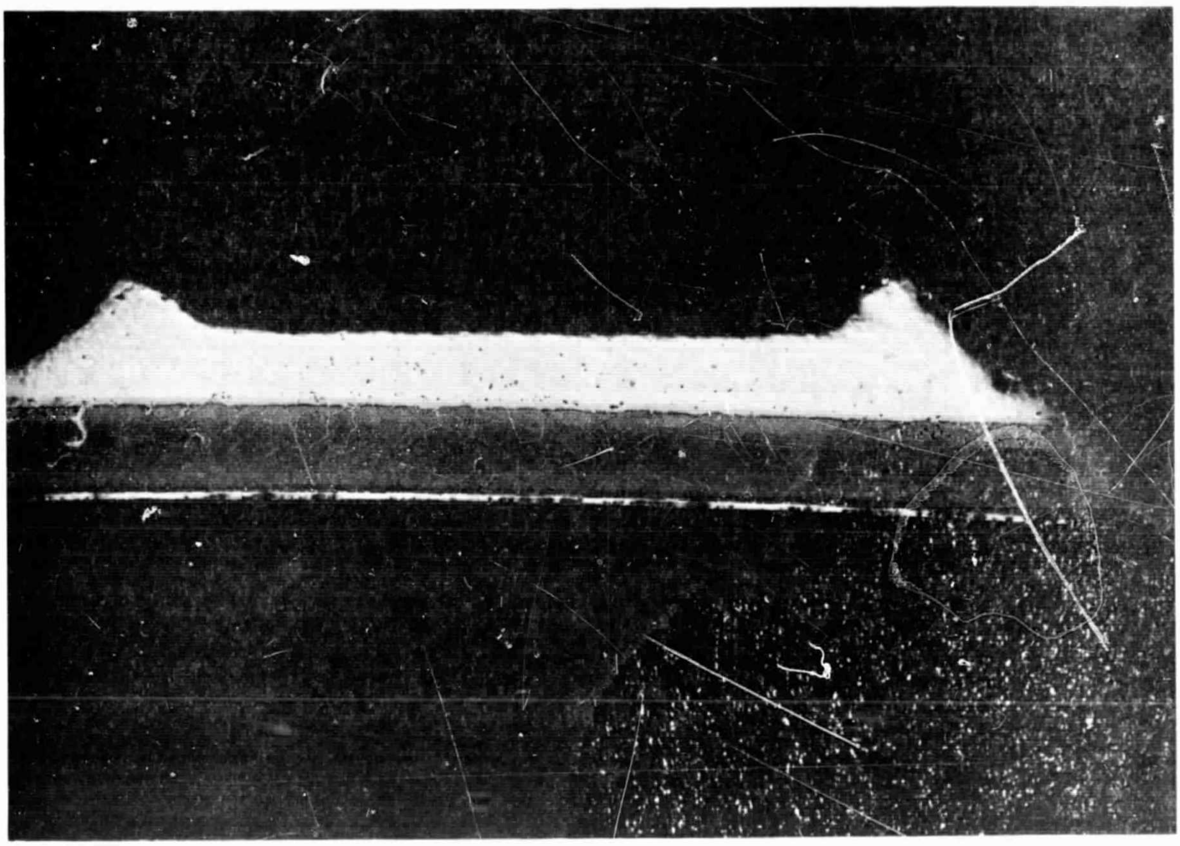


Figure 33 Section Through CM50/U700
Cruciform Stress Rupture Specimen #3 (Cooling Effect)
Failed in CM50, 50X

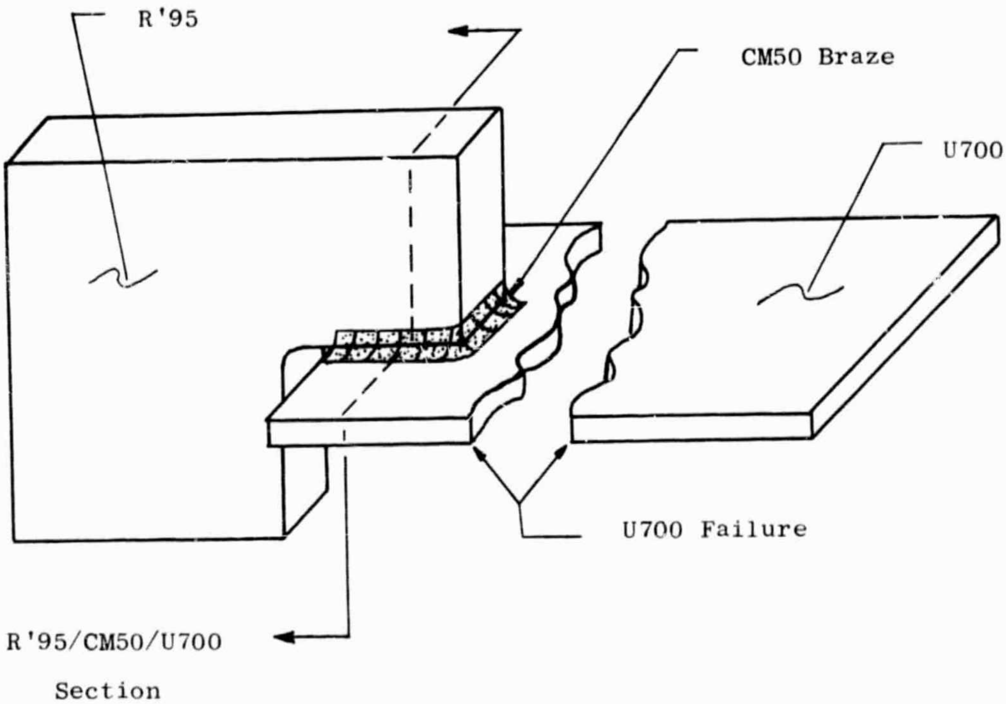


Figure 34. Micro Structure Location
Cruciform Fatigue Specimen #5
(A=0.98, 1200 F)

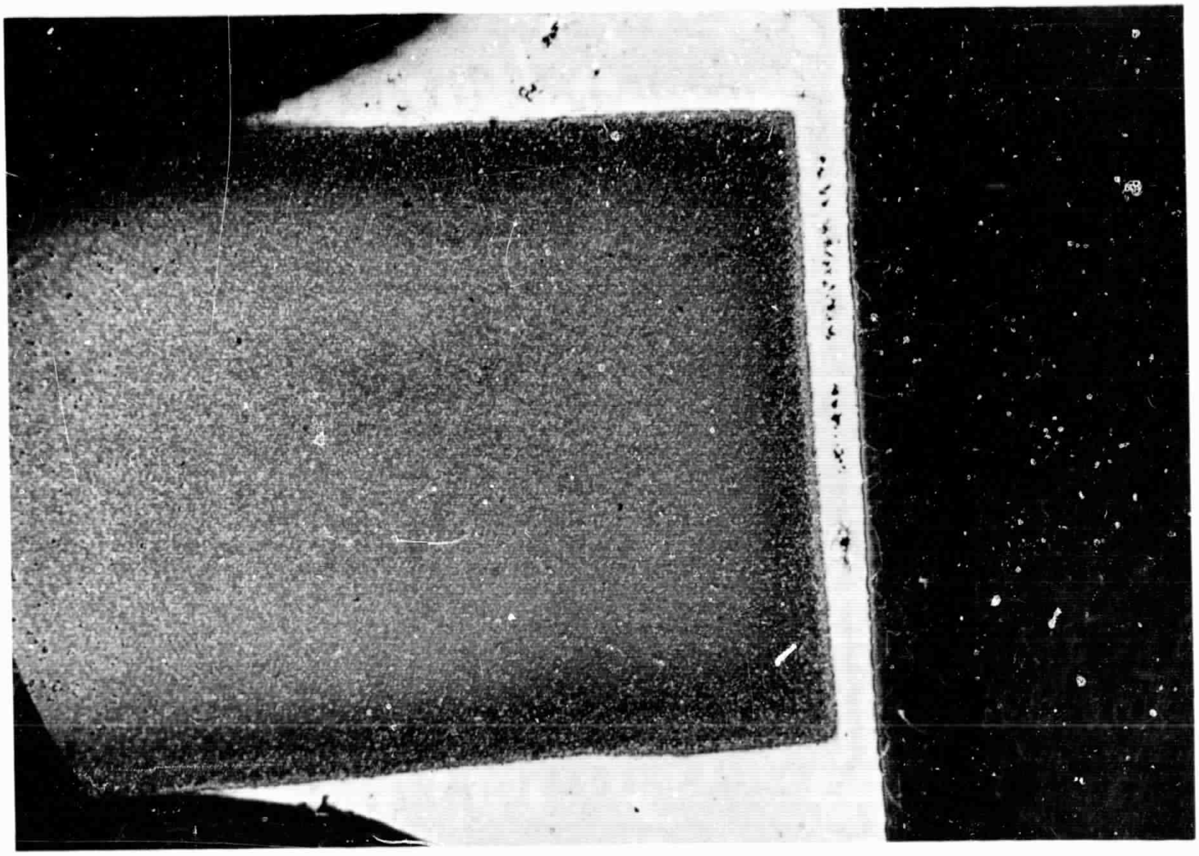


Figure 35 Section Through R'95/CM50/U700
Cruciform Fatigue Specimen #5 (A=0.98, 1200 F)
Failed in U700, 50X

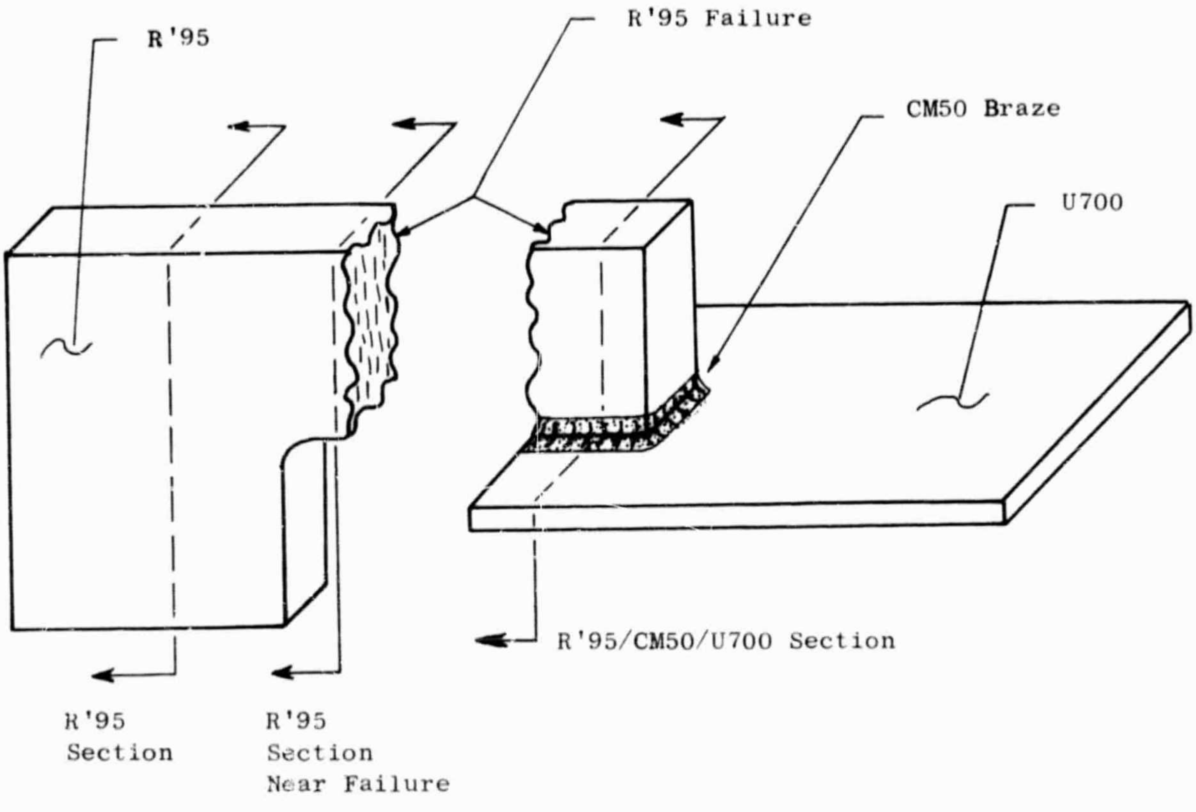


Figure 36. Micro Section Locations Cruciform
Fatigue Specimen # 3
(A=0.98, 1200 F)

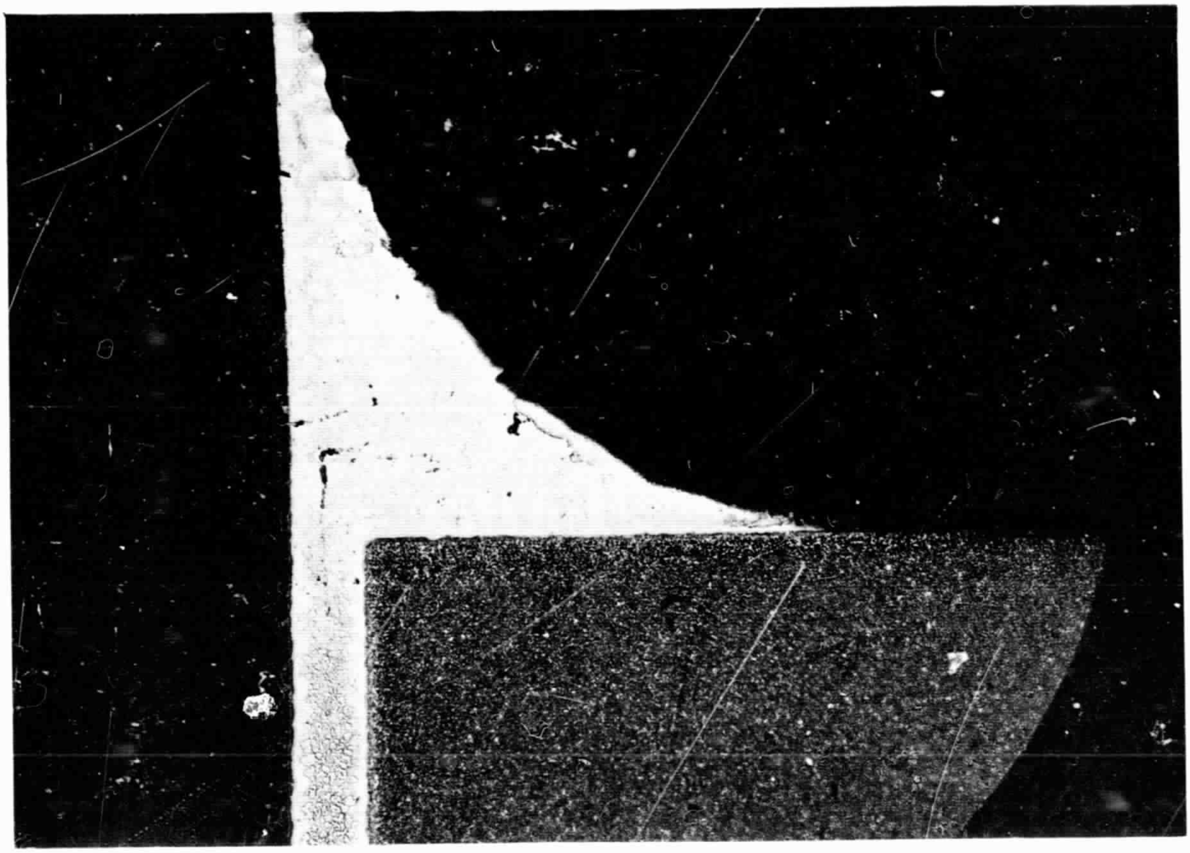


Figure 37 Section Through R'95/CM50/U700
Cruciform Fatigue Specimen #3 (A=0.98, 1200 F)
Failed in R'95, 50X

Or

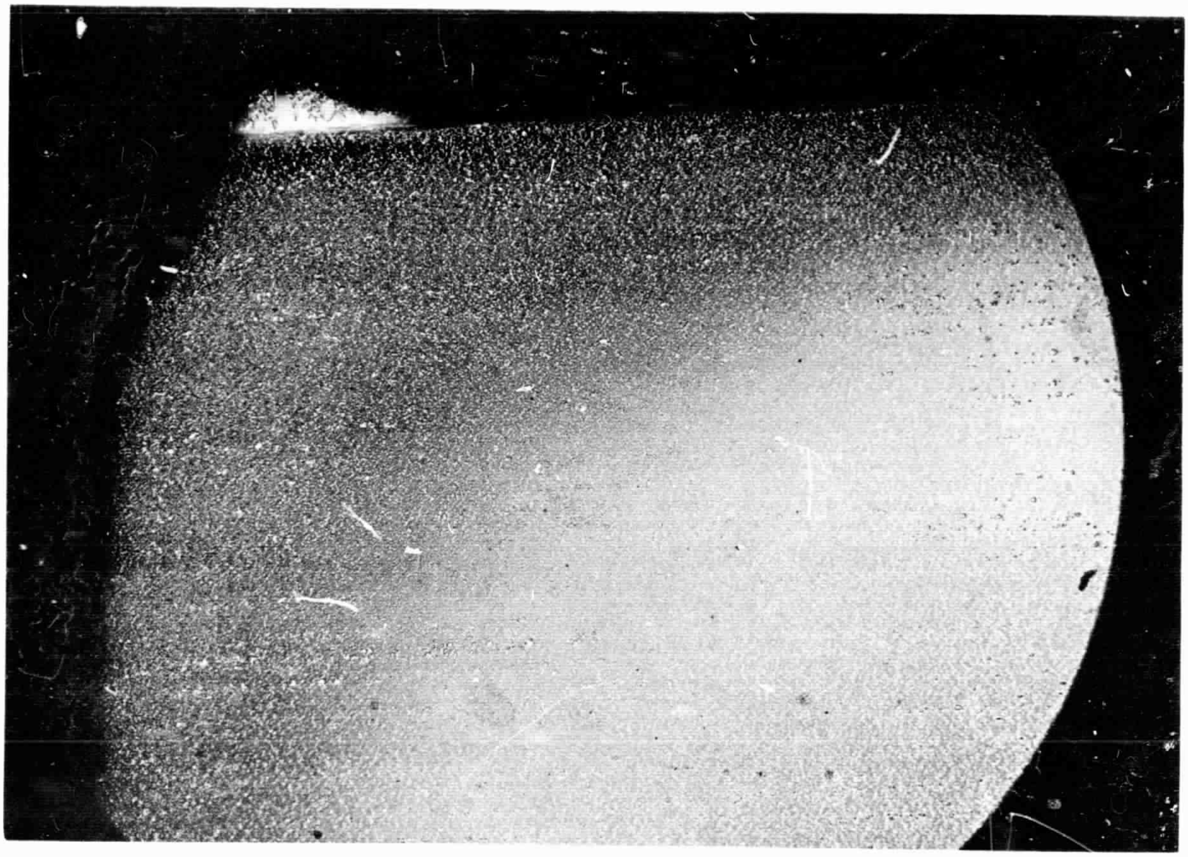


Figure 38 Section Through R'95
Cruciform Fatigue Specimen #3 (A=0.98, 1200 F)
Failed in R'95, 50X

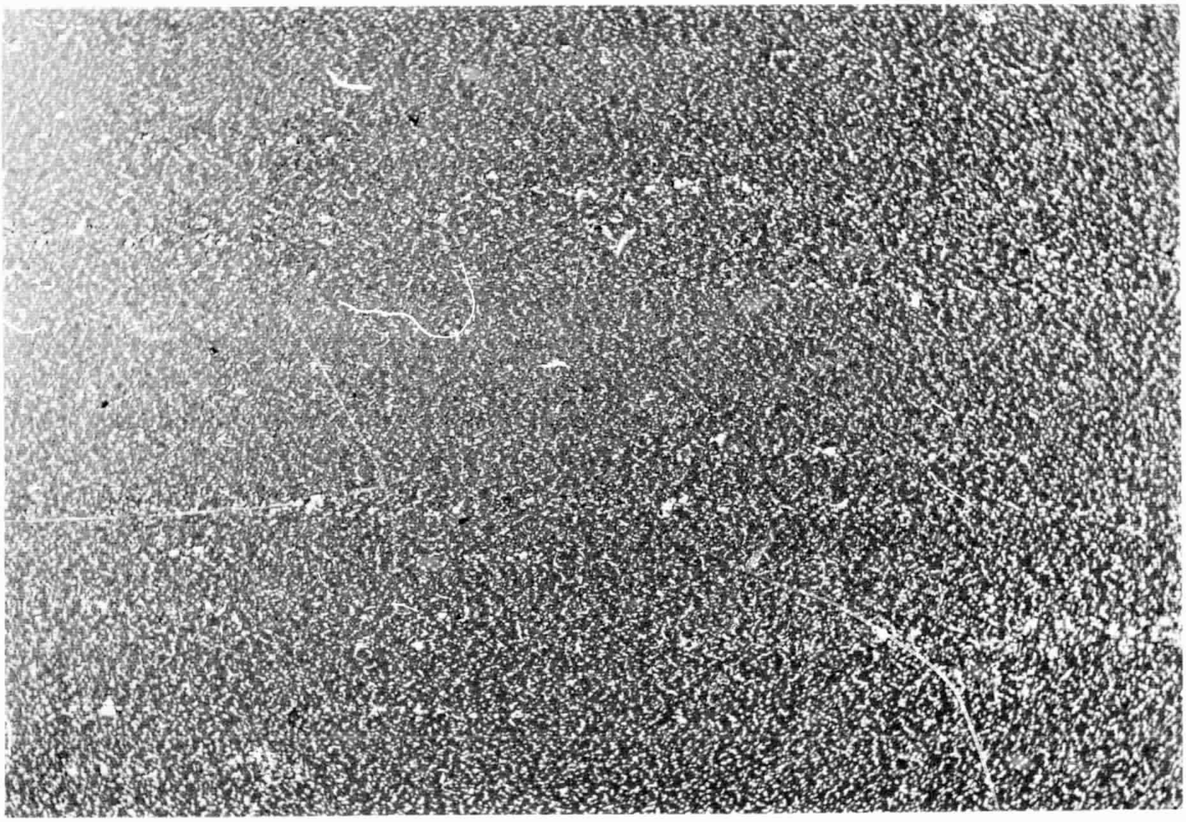


Figure 39 Section Through R'95 Adjacent to Fracture Cruciform Fatigue Specimen #3 (A=0.98, 1200 F) Failed in R'95, 100X

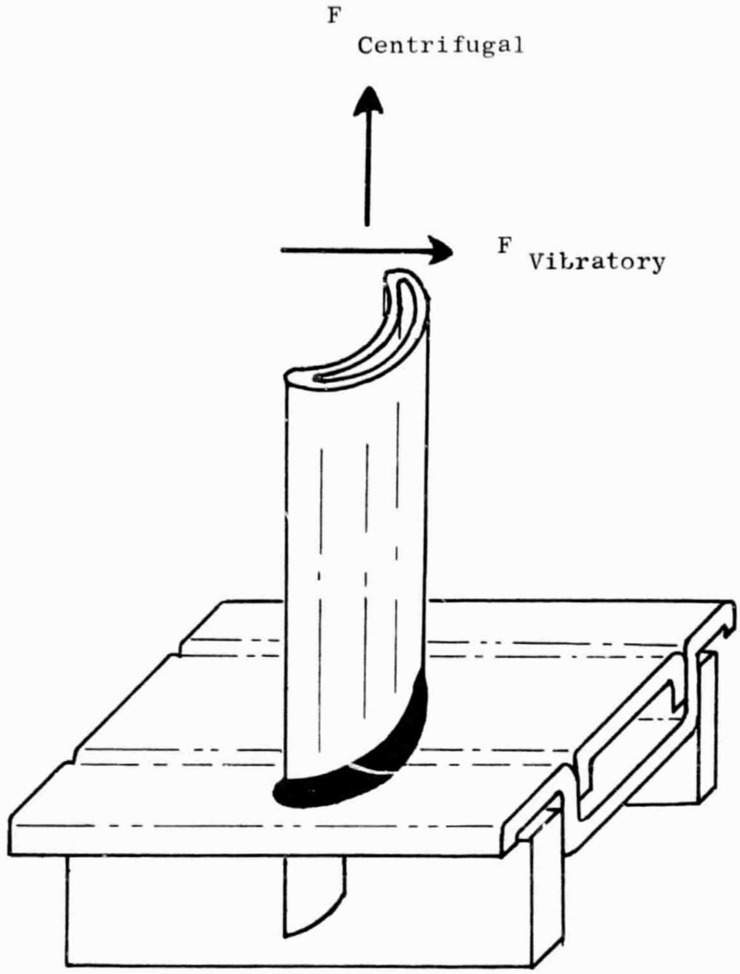


Figure 40. Overall Turbine Blade Support Structure

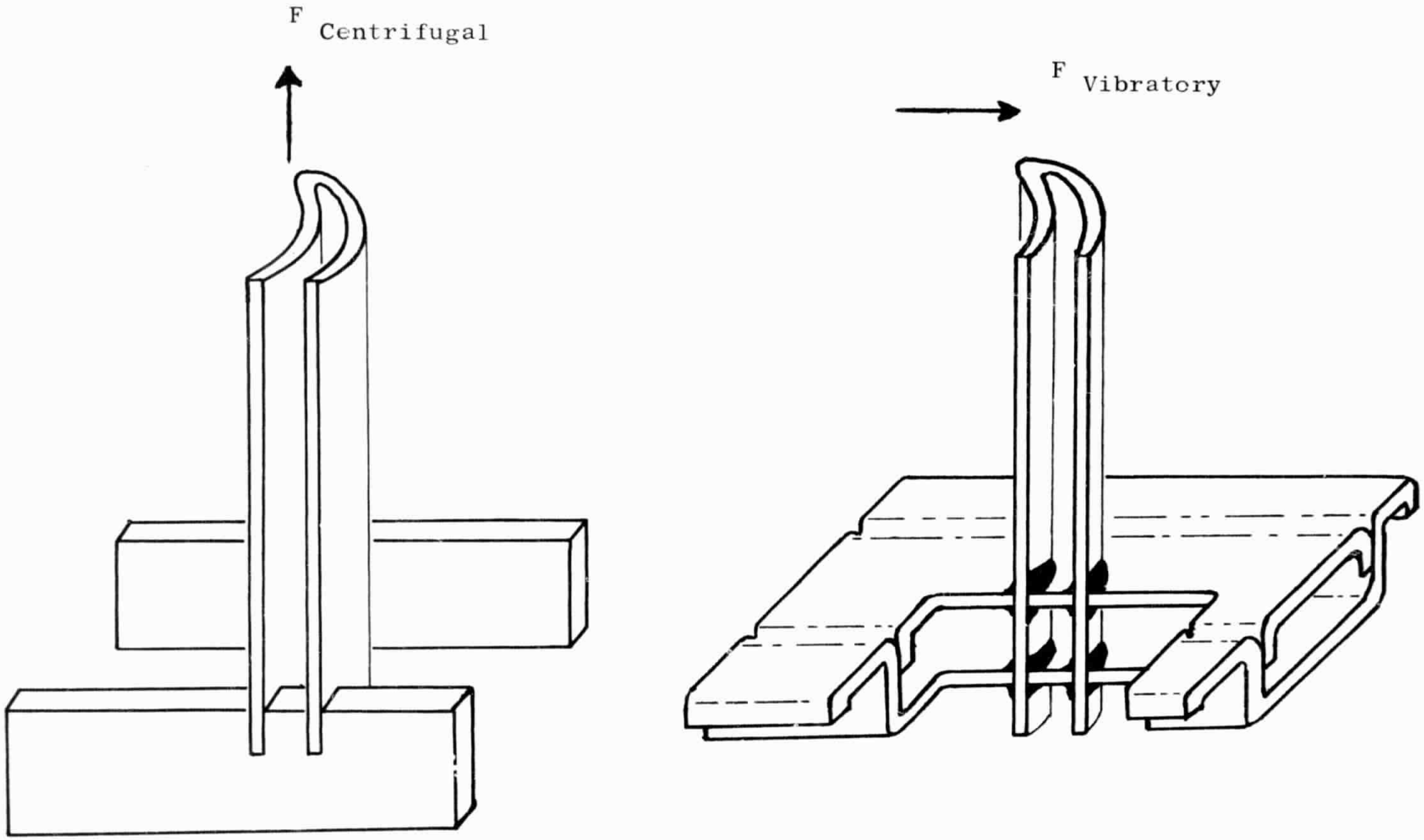


Figure A

Figure B

Figure 41. Local Turbine Blade Support Structure

Centrifugal Loading

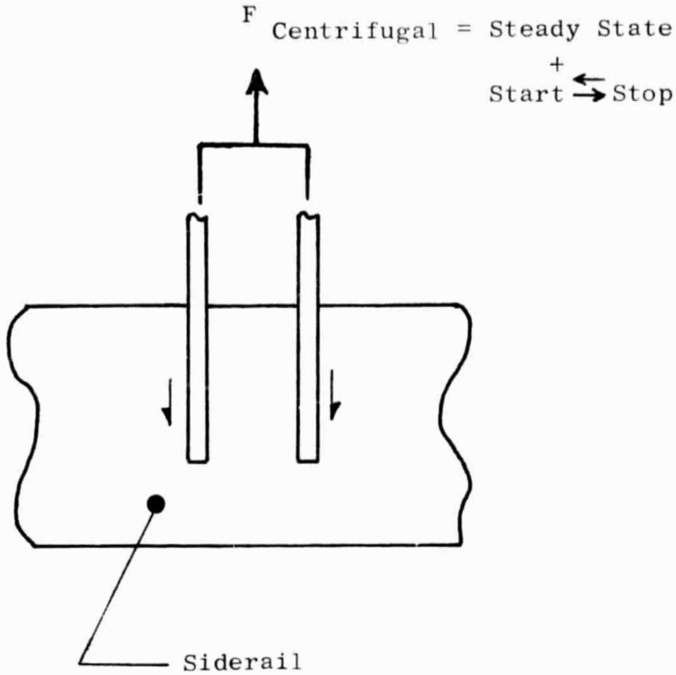


Figure A

Vibratory Loading

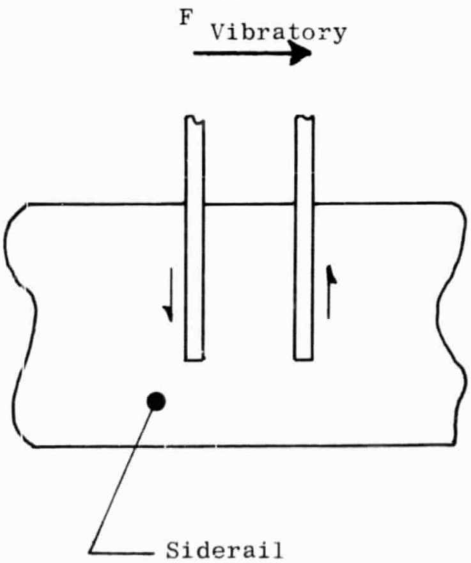


Figure B - Conservative Analysis

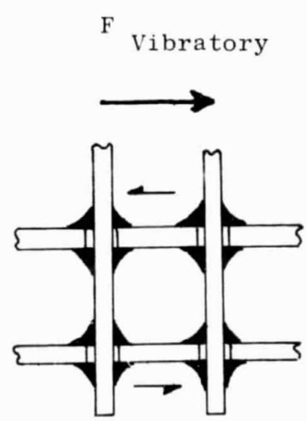


Figure C - Realistic Analysis

Figure 42. Free Body Diagrams, Turbine Blade Support Structure

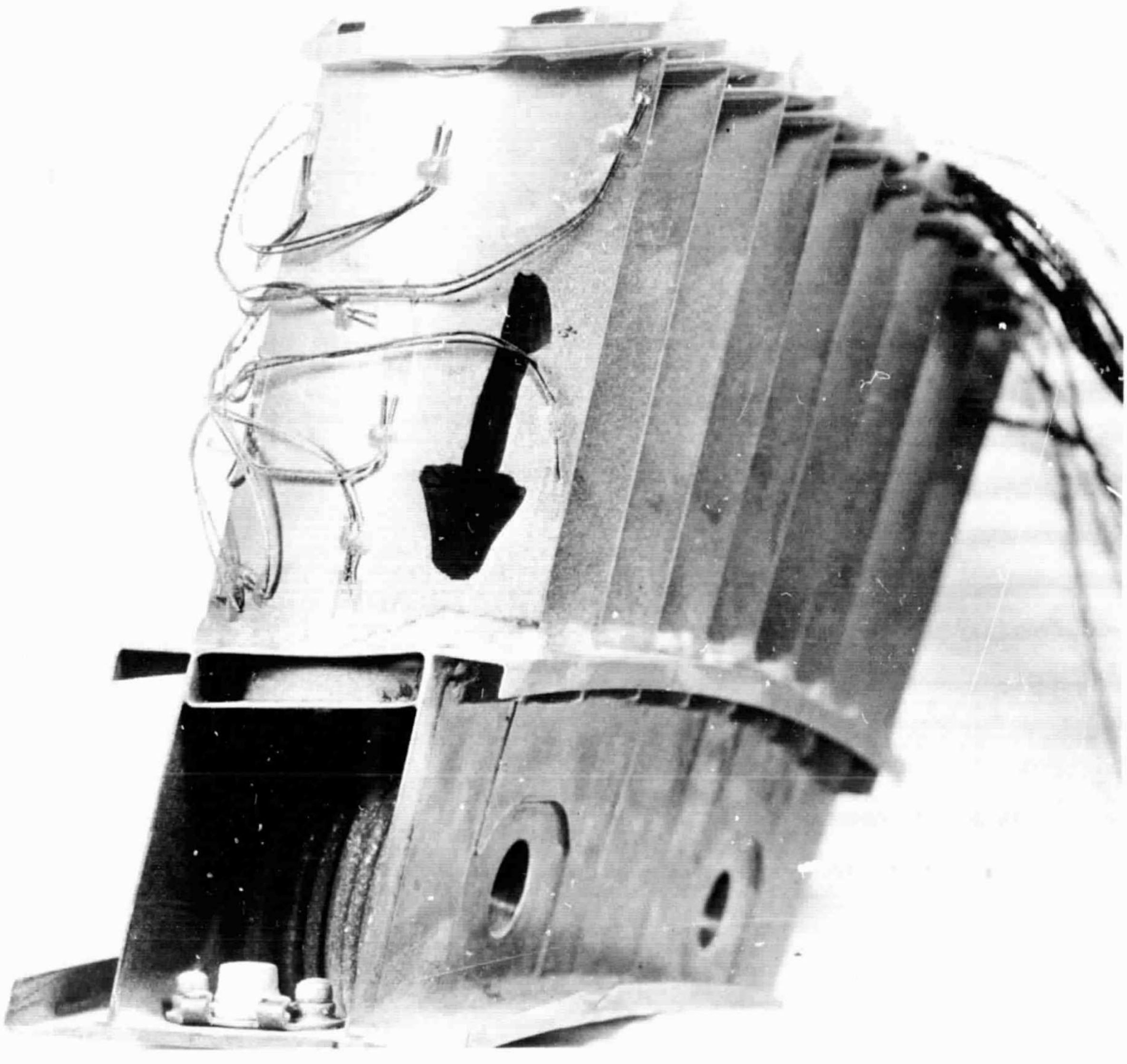


Figure 43 Bucket #1 Leading Edge Crack
First Flex Endurance Test
LF336 Turbine Carrier Bench Test

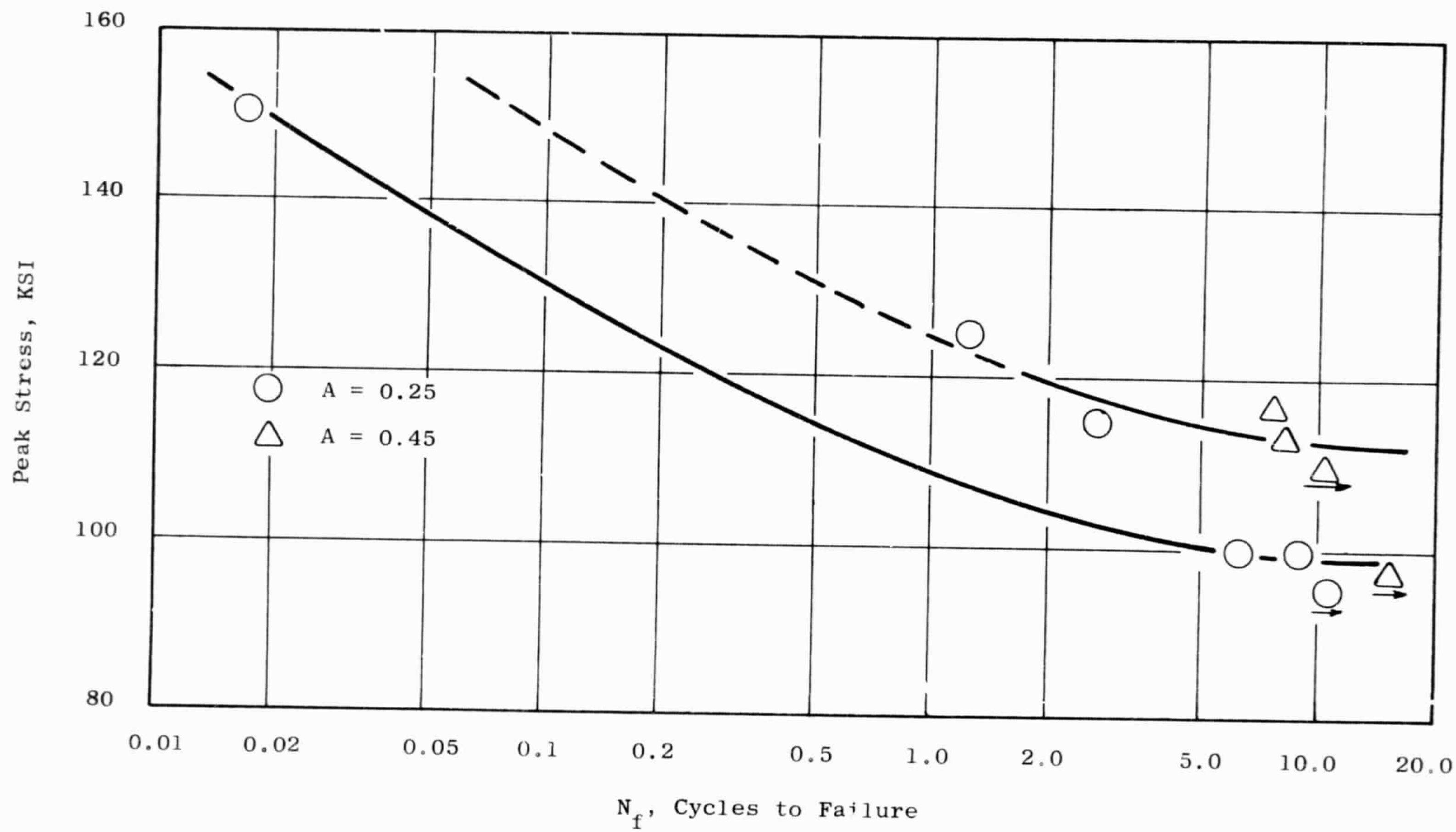


Figure 44. Parent Metal U700 High Cycle Fatigue, 1400°F, Axial-Axial Data

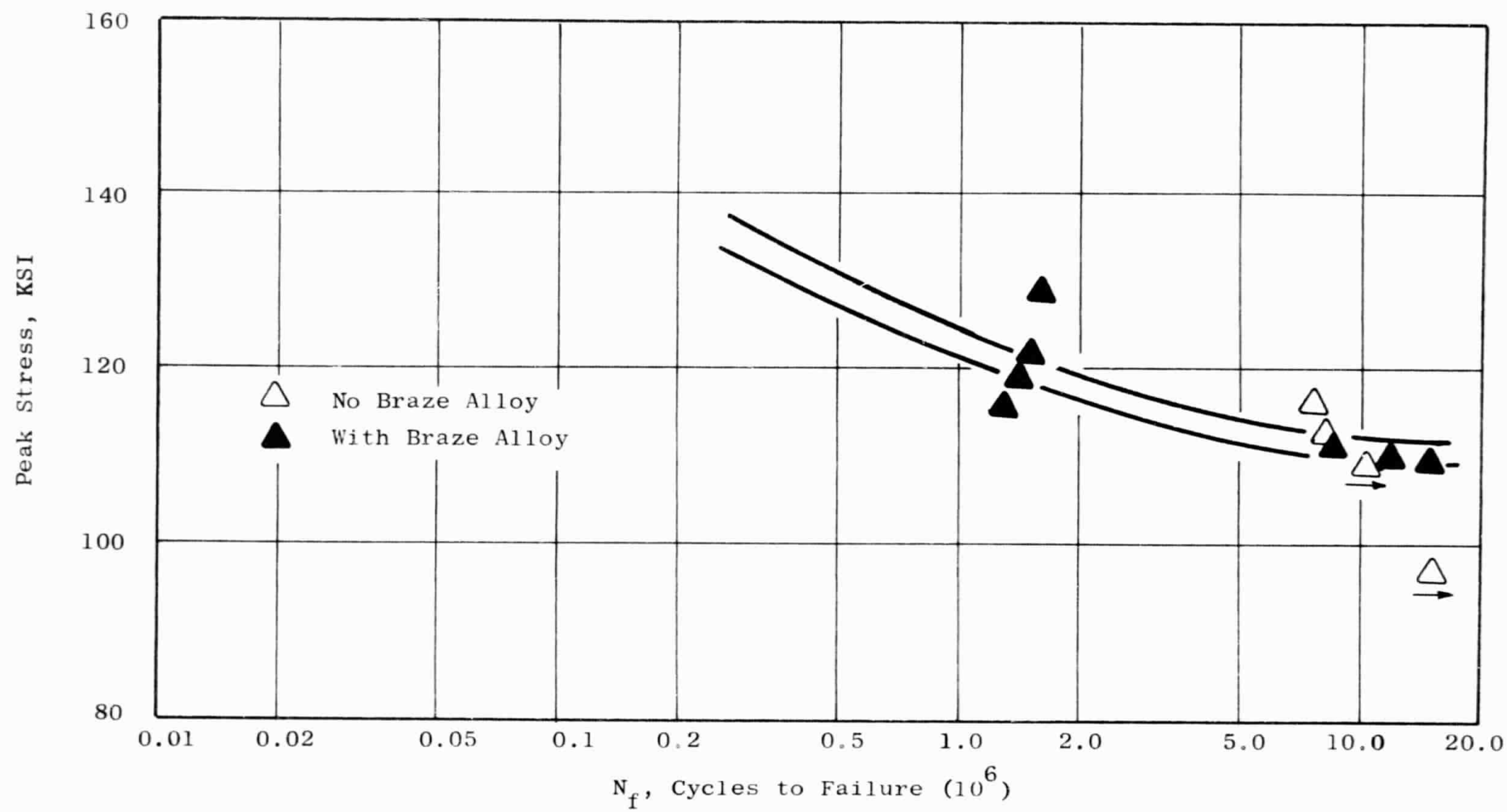


Figure 45. Effect of Surface Braze Alloy on Parent Metal U700 High Cycle Fatigue, 1400 F, A = 0.45

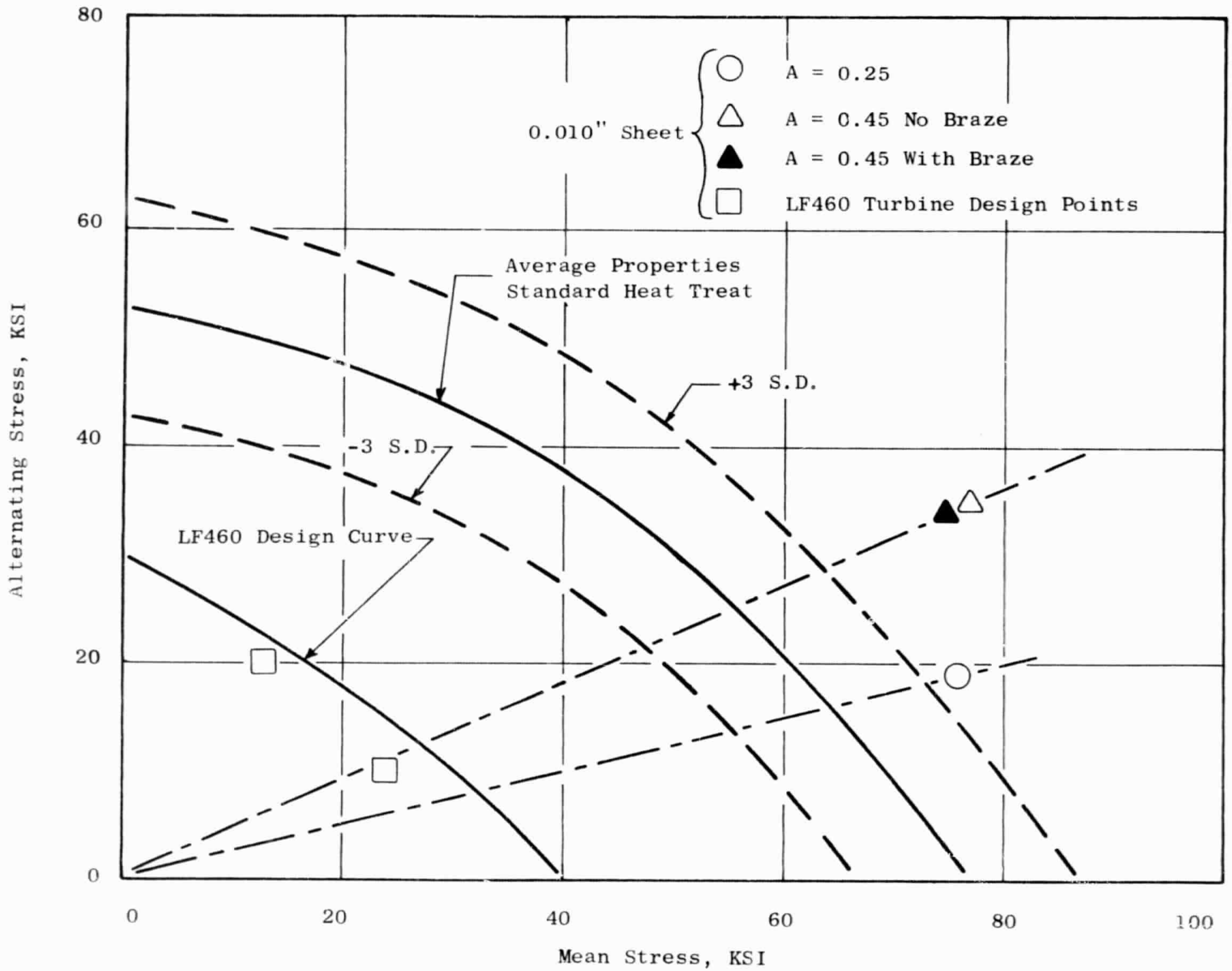


Figure 46. U700 Stress Range Diagram, 1400 F

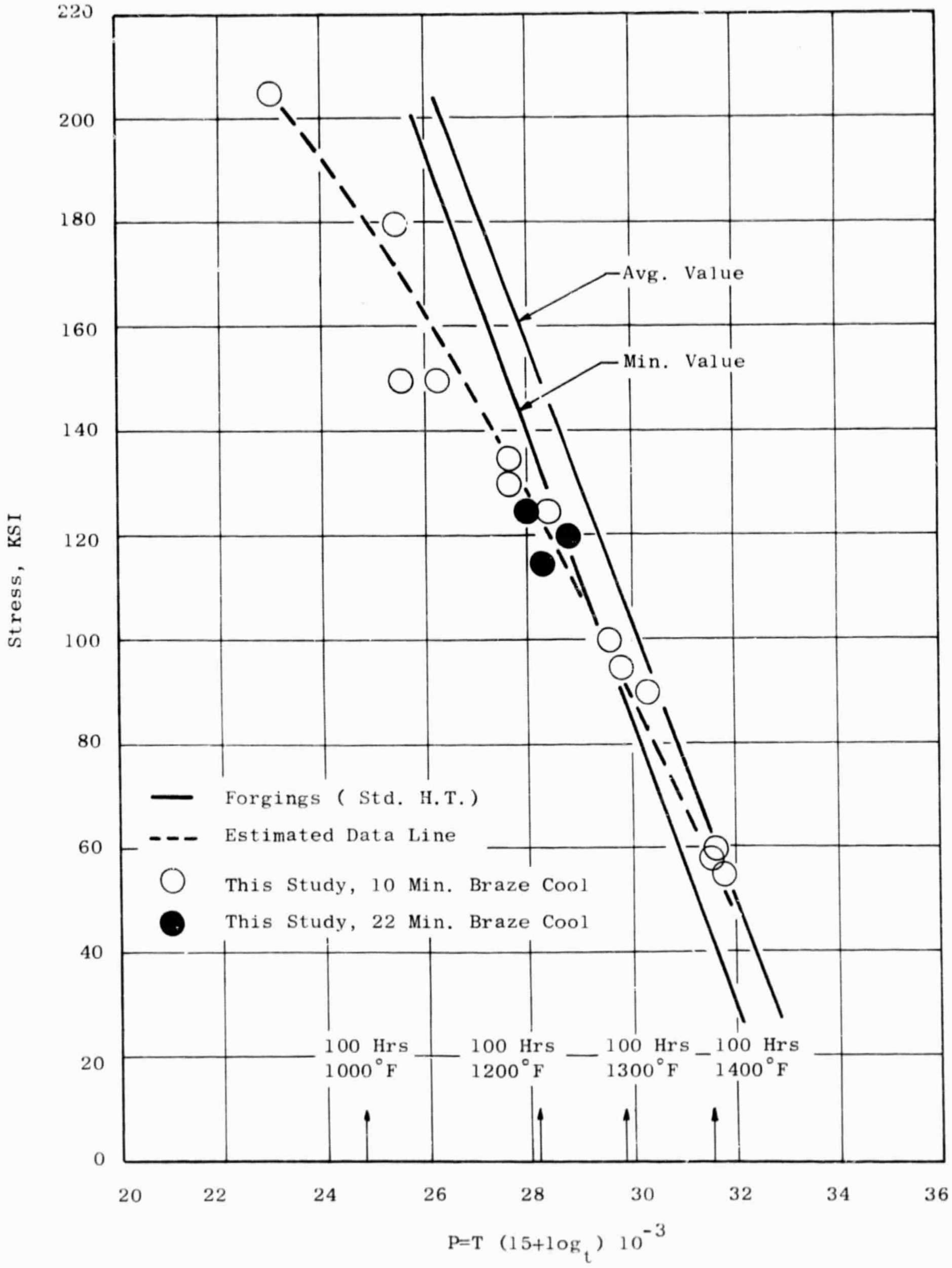


Figure 47. Parent Metal R'95 Stress Rupture Strength

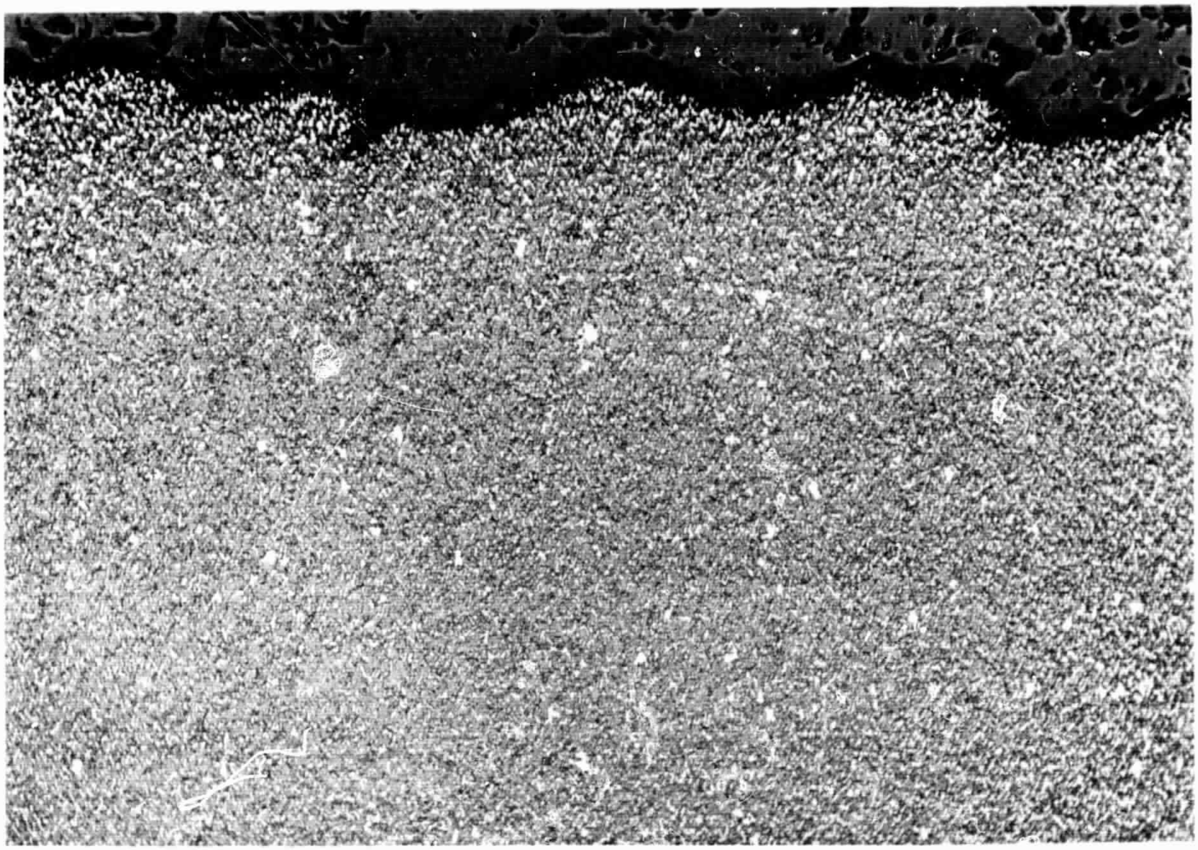


Figure 48 Section Through R'95 at Failure Location
Parent Metal Stress Rupture Specimen
with 22 Minute Cool Cycle, 100X

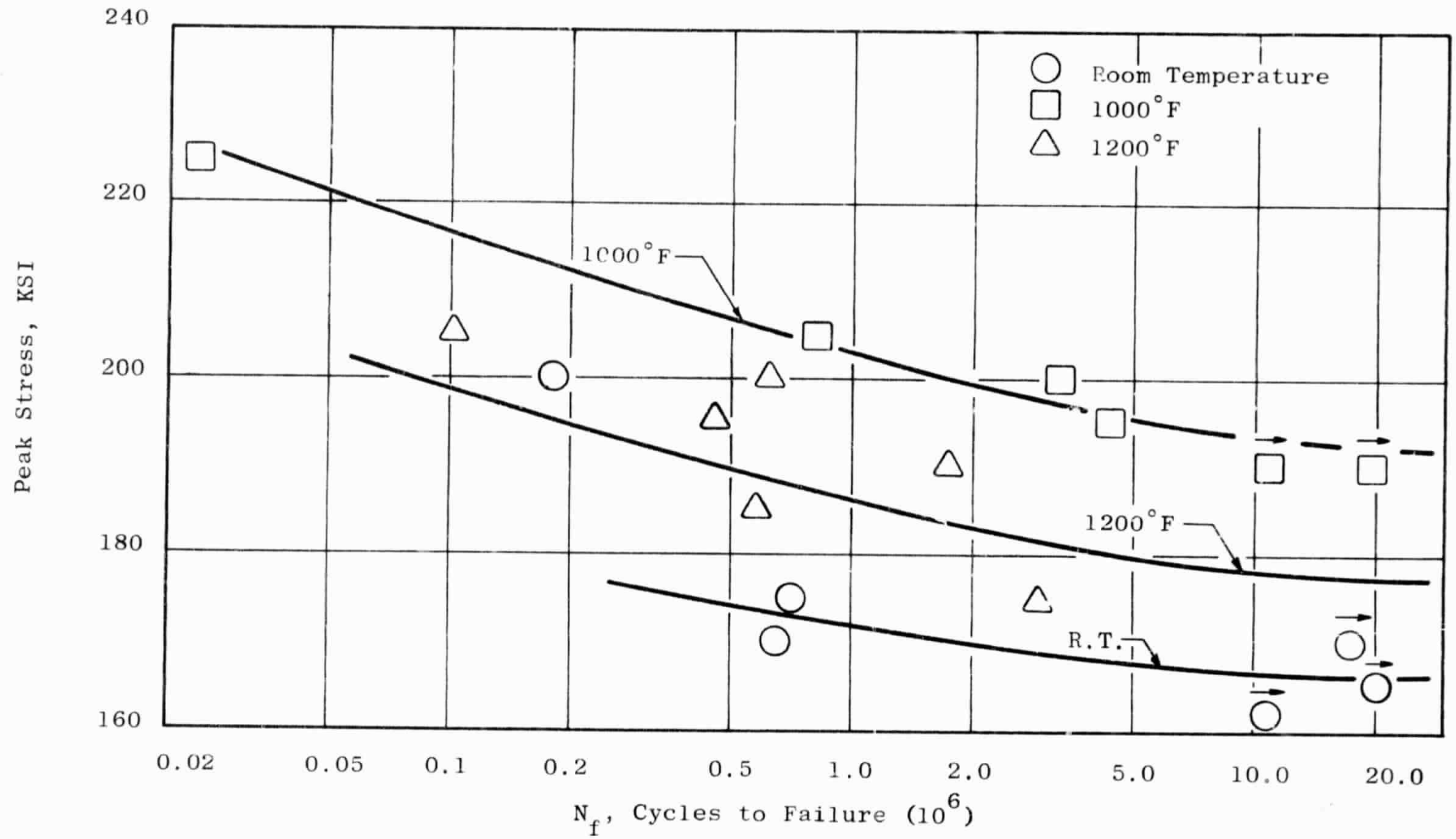


Figure 49. Parent Metal Rene'95 High Cycle Fatigue, A=0.25

ER

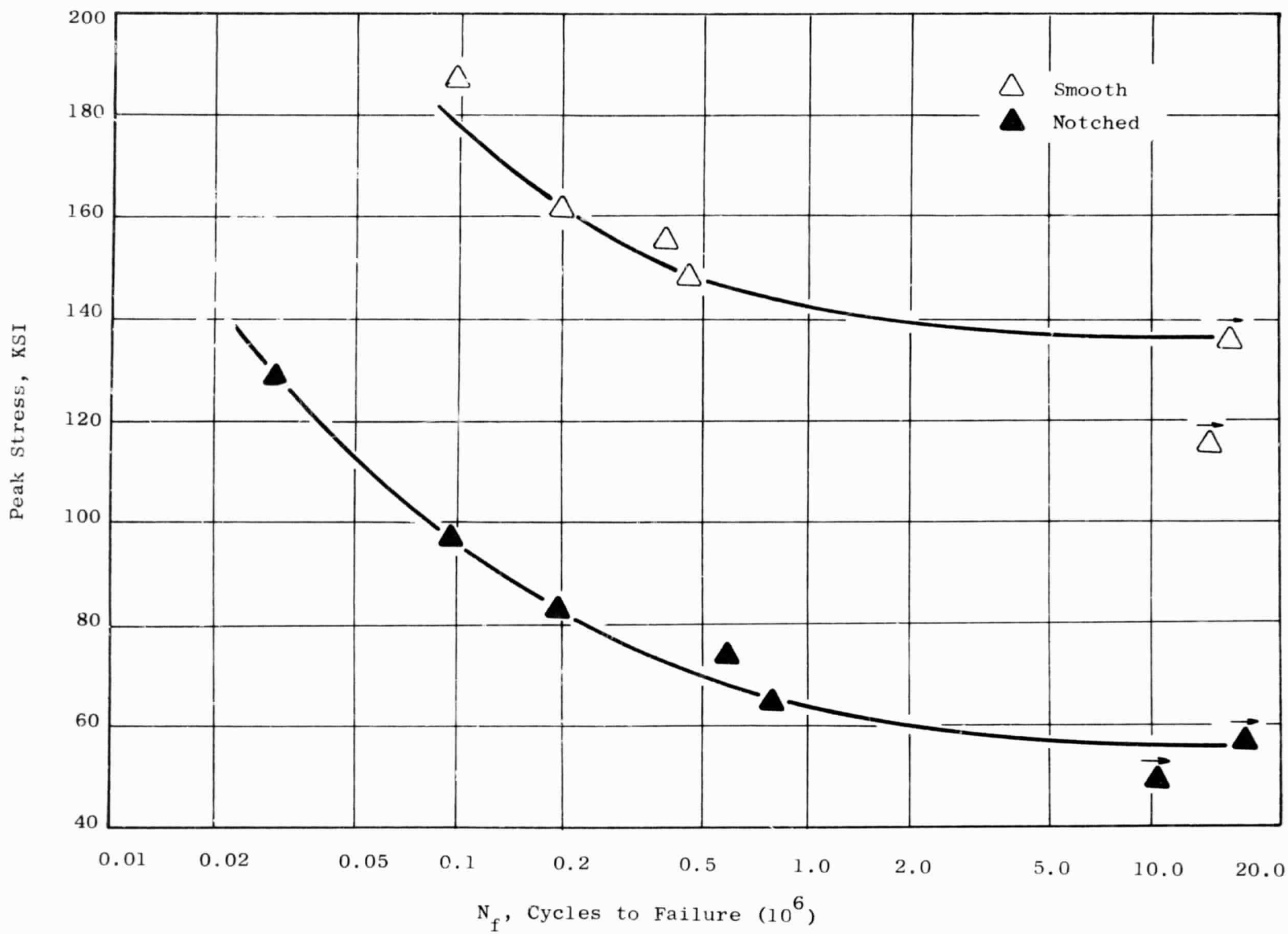


Figure 50. Parent Metal Rene'95 High Cycle Fatigue, Room Temperature, Axial-Axial Data, A=0.45

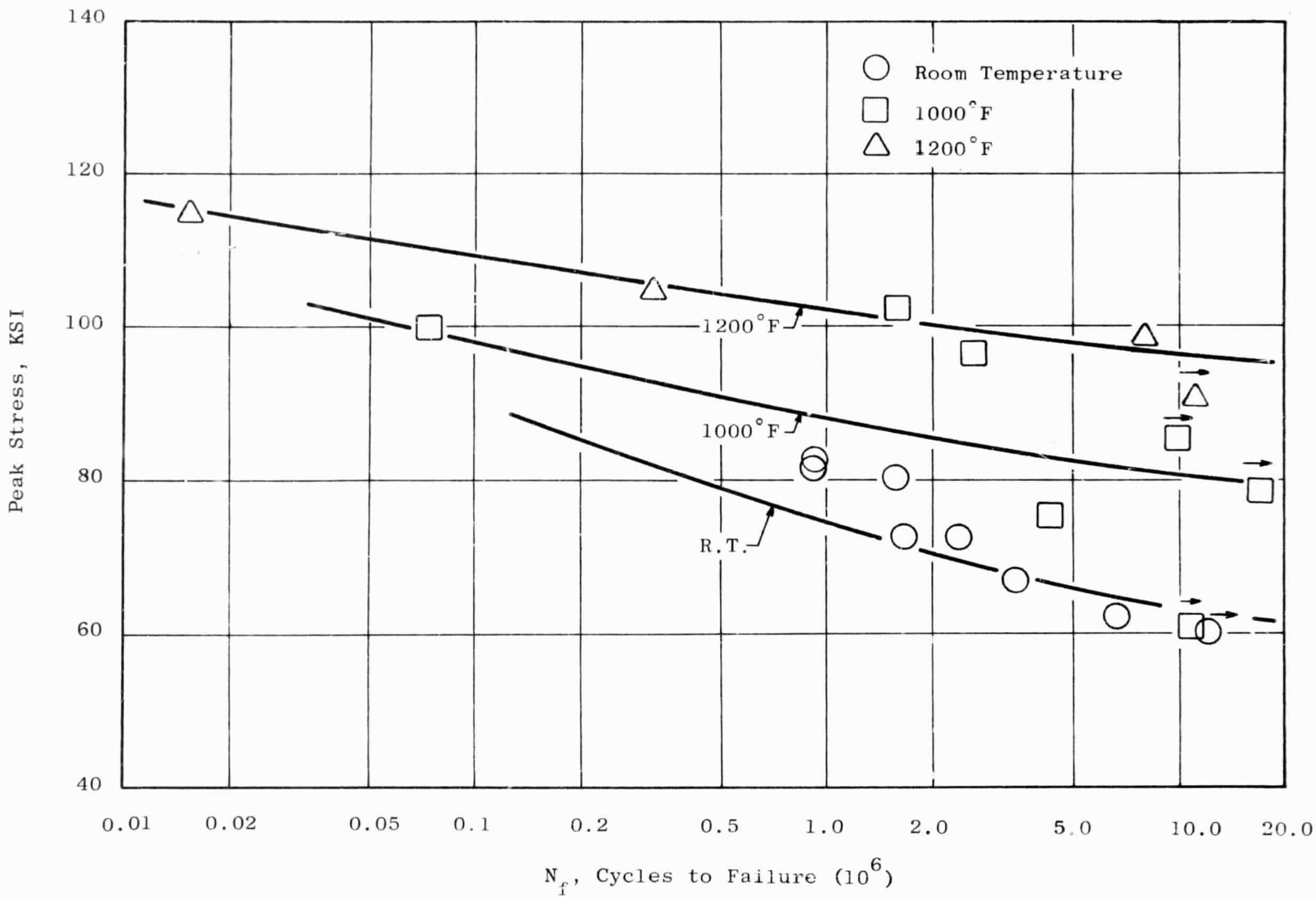


Figure 51. Parent Metal Rene'95 High Cycle Fatigue, A=∞

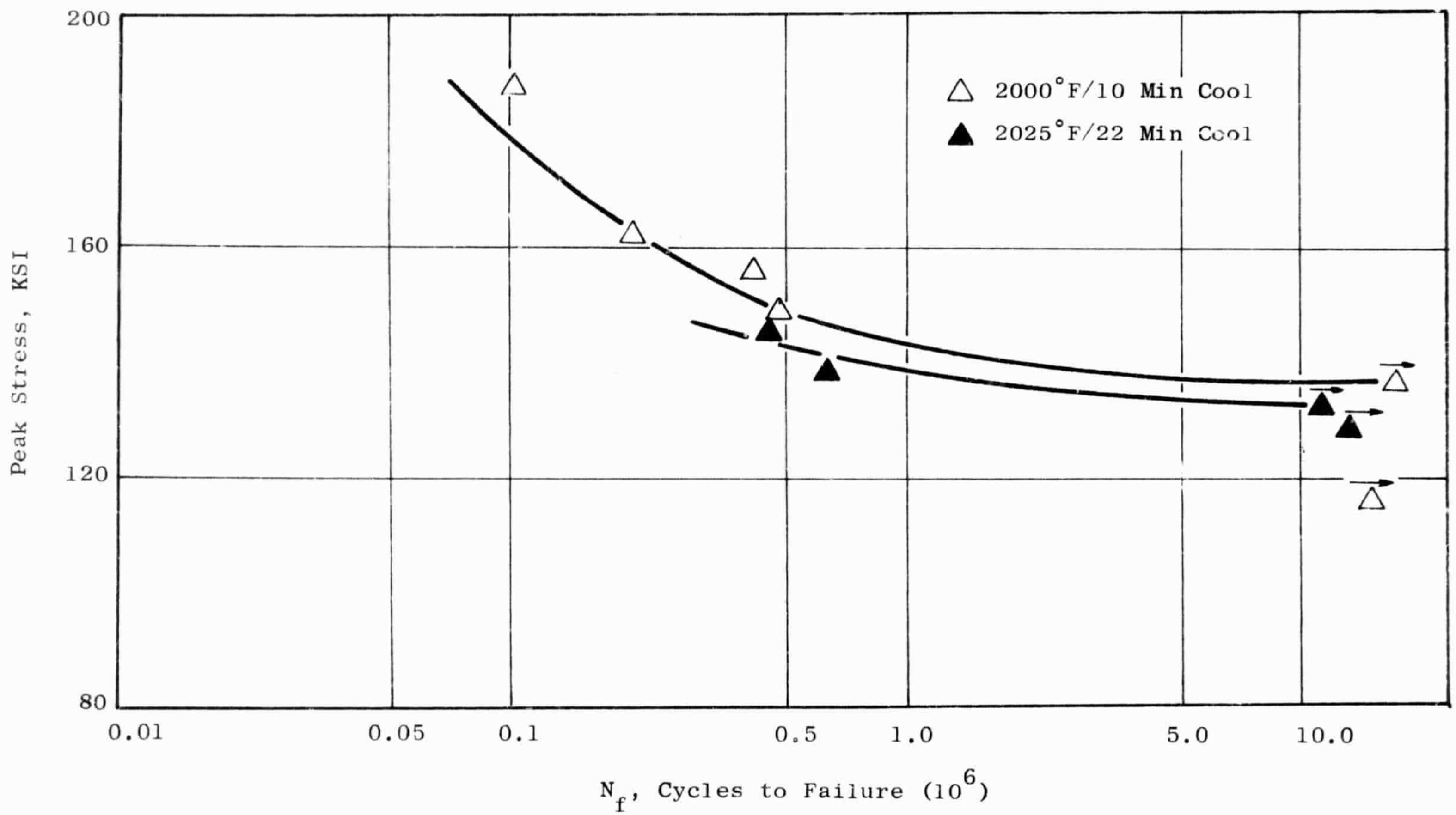


Figure 52. Effect of Cooling Rate on Parent Metal Rene' 95 High Cycle Fatigue Room Temperature, A = 0.45, Axial-Axial Data

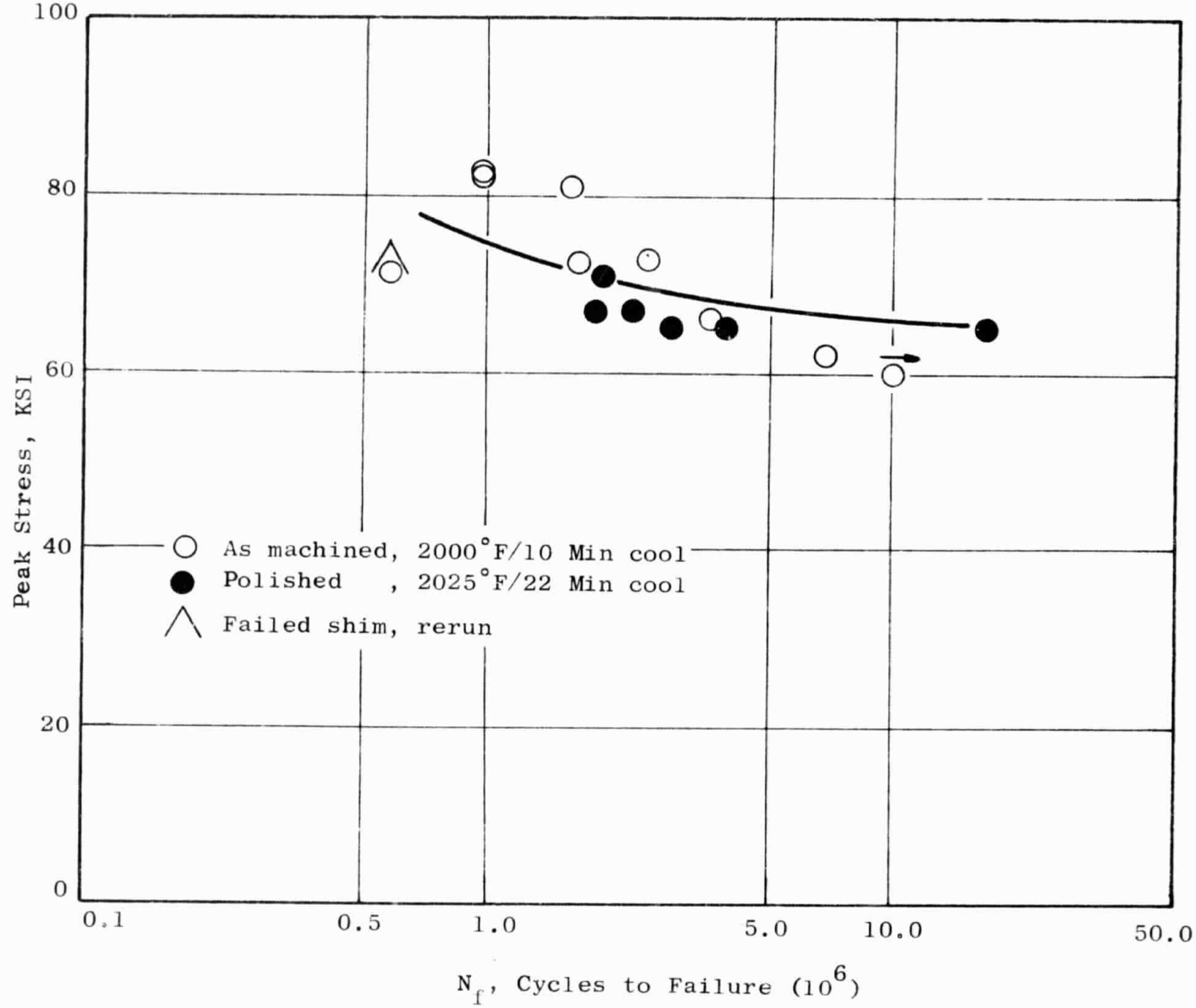


Figure 53. Effect of Surface Preparation and Cooling Rate on Parent Metal Rene' 95 High Cycle Fatigue Room Temperature, A = ∞ Bending Data

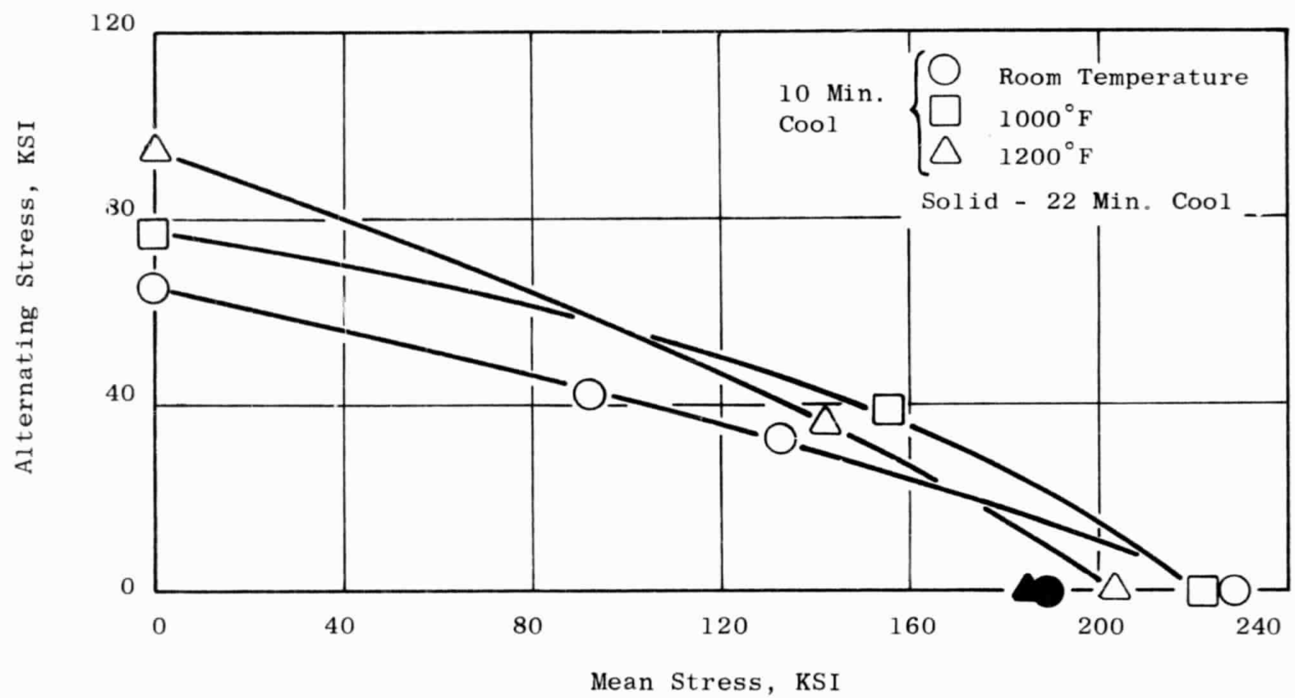


Figure 54. Parent Metal Rene'95 High Cycle Fatigue Stress Range Diagram

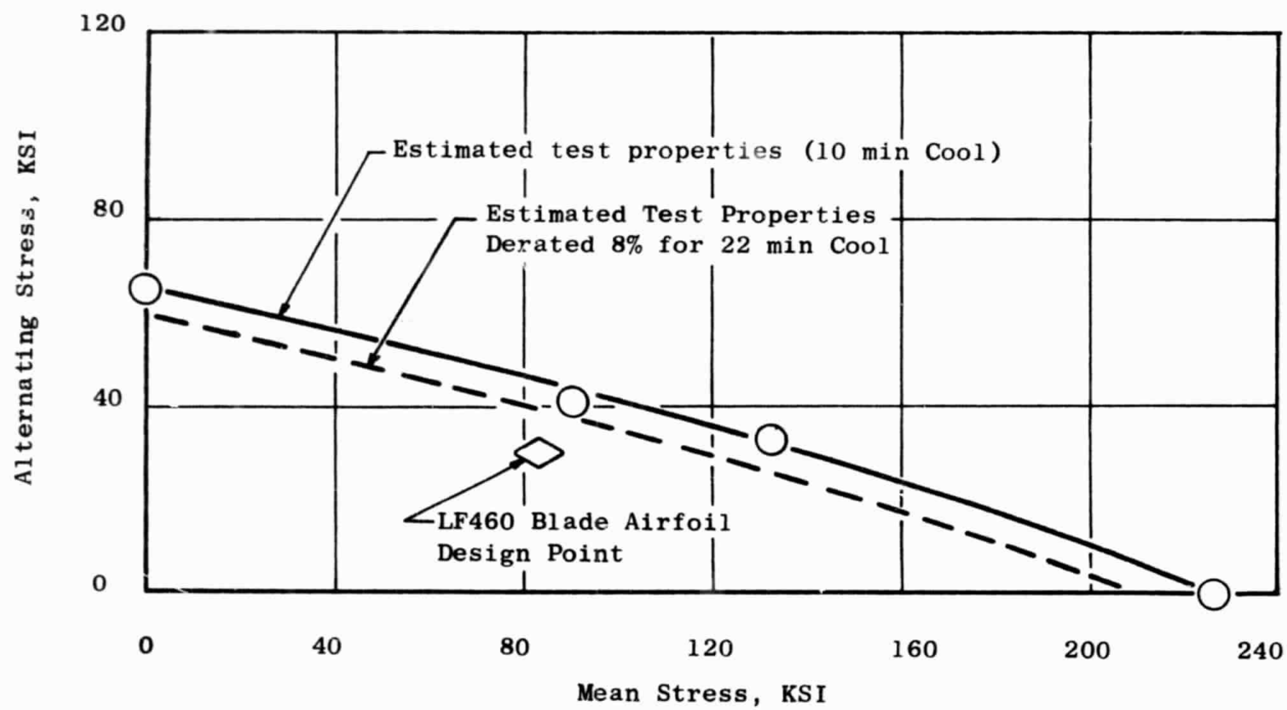


Figure 55. Room Temperature Parent Metal Rene'95 High Cycle Fatigue Stress Range Diagram

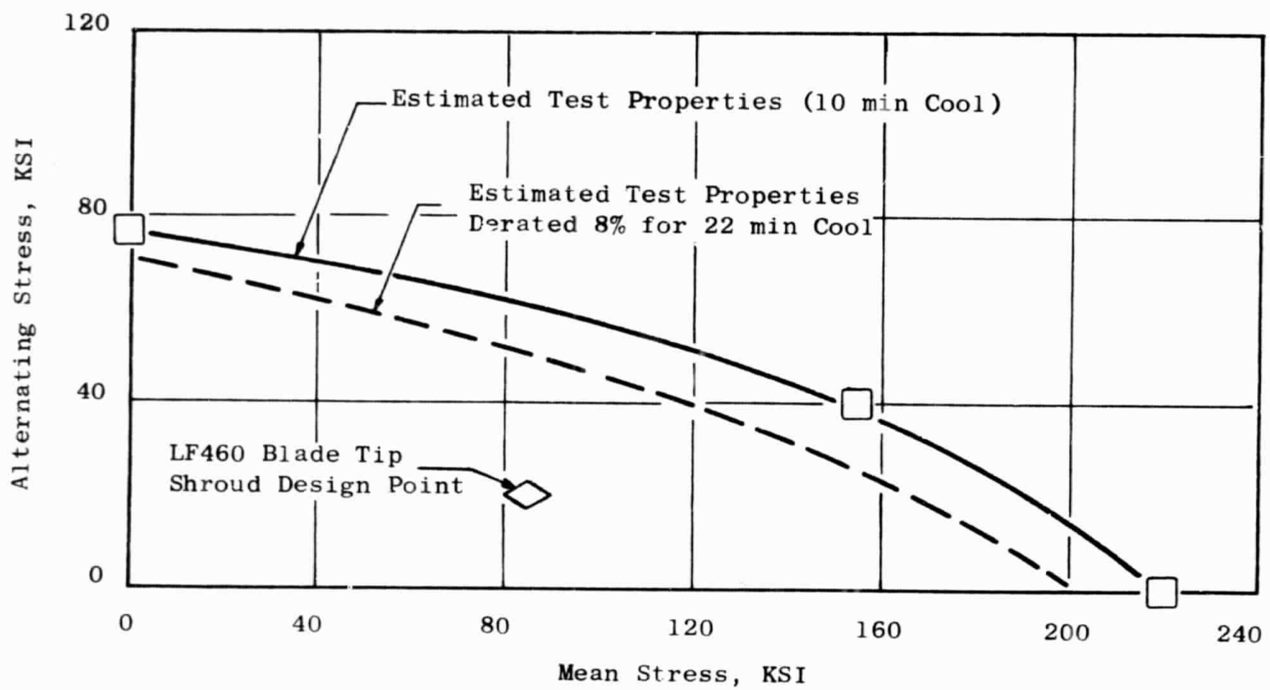


Figure 56. 1000°F Parent Metal Rene'95 High Cycle Fatigue Stress Range Diagram

Figure 57 Duplex Microstructure of Standard Processed R'95 Forgings Coarse Unrecrystallized Grains Surrounded by a Network of Fine Recrystallized Grains, 500X

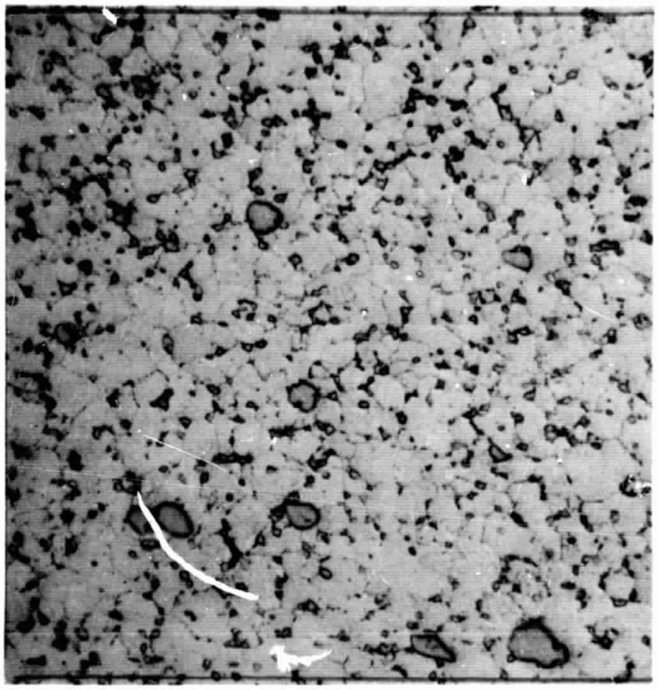


Figure 58 Uniform Fine Grained Microstructure of Standard Processed R'95 Bar Stock, 500X

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15. Supplementary Notes

16. Abstract

The René 95/Coast Metal 50/Udimet 700 braze joint and parent metal evaluation program obtained design stress data for rupture, high and low cycle fatigue, and U700 thin wall effects. Properties at room temperature and at elevated temperatures up to 1400°F were evaluated.

The program was directed towards advanced lift fan applications and the resulting data, when applied to the LF460 fan, shows the design is feasible. In addition, the technical and material data for brazed joints connecting René 95 and U700 with coast metal 50 braze alloy are of a general nature and have broad design application.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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